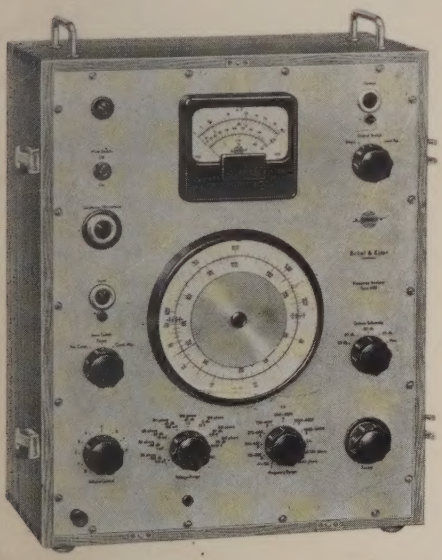
R & M

2105

INSTRUCTIONS AND APPLICATIONS

Frequency Analyzer Type 2105



A Multipurpose Audio Frequency Analyzer applicable to all kinds of acoustical measurements; for vibration-technique research, for measurement of sound pressures and sound levels with the aid of a precision microphone, for analyzing electrical voltages, as indicating instrument in all accurate bridge measurements, etc. etc.

- Beat frequency oscillators
- Low frequency oscillators
- Deviation test bridges
- Strain gauge apparatus
- Frequency measuring bridges
- Distortion measuring bridges
- Heterodyne voltmeters
- Audio frequency spectrometers
- Frequency analyzers
- Level recorders, a. c. and d. c.
- Automatic frequency response recorders
- Automatic A. F. spectographs
- Logarithmic potentiometers
- Noise level potentiometers
- Recording paper
- Polar diagram recorders
- Vacuum tube voltmeters
- Wide range vacuum tube voltmeters
- Diode voltmeters
- D. C. voltmeters
- Megohmmeters
- Microphone amplifiers
- Impact sound generators
- Acoustic standing wave apparatus
- Artificial ears
- Condenser microphones
- Microphone calibration apparatus
- Vibration pick-ups
- Integration networks
- Rotary selectors
- Universal selectors
- Frequency response tracers
- Conductivity meters
- Electronic counters
- Counting rate meters
- Impulse generators
- Portable dose rate meters
- Portable counting rate meters
- G. M. tubes & accessories

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FREQUENCY ANALYZER

type 2105

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Description

The Analyzer Type 2105 is a selective tube voltmeter, primarily designed for acoustical and electro-acoustical measurements, as for example recording of vibration and noise spectograms, measurements of sound pressures, noise and vibration levels, and as a selective amplifier when measuring reverberation times. However, the instrument can with great advantage be used in pure electrical measurements, for example as indicator in bridge measurements and to analyze complex voltages.

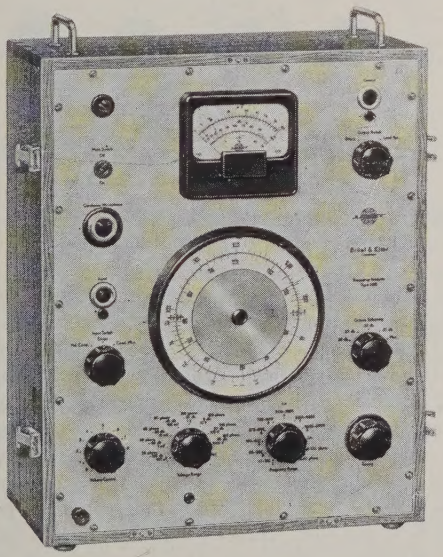


Fig. 1. Photo of the Constant-percentage Bandwidth Analyzer type 2105.

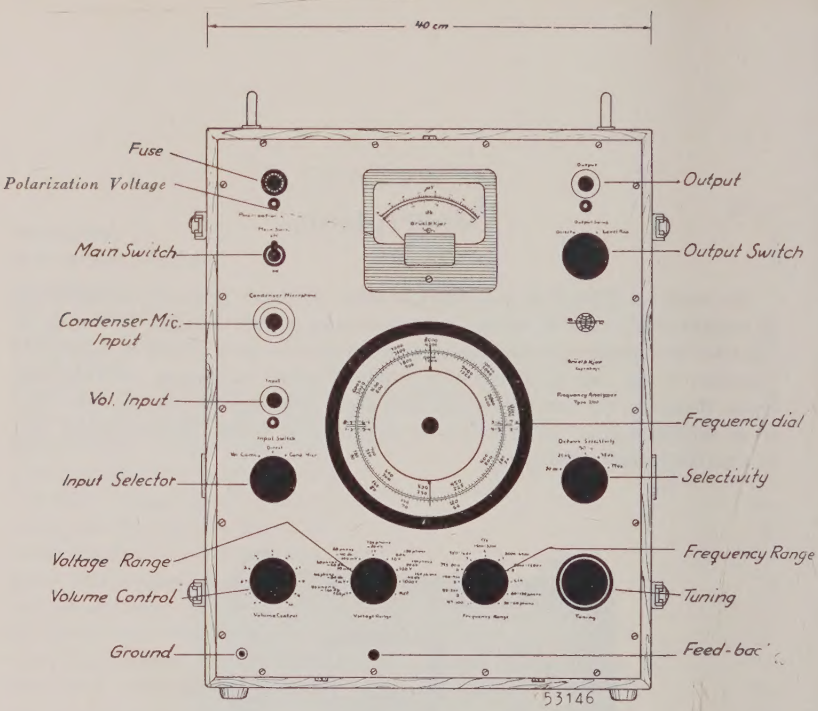


Fig. 2. Drawing indicating the various controls and the dimensions of the apparatus. Valid for serial numbers above 3370.

The Analyzer contains a four-stage a.f. amplifier followed by a moving coil instrument. The first two amplifier tubes are heated by d.c. in order to reduce the hum level. The d.c. voltage is taken from a special rectifier in the apparatus. The requisite selectivity is obtained through negative feedback over two stages through an R.C. filter. Fig. 3 shows a block diagram of the instrument.

The input jack of the apparatus is connected to an attenuator marked "Voltage Range" by means of which the sensitivity can be reduced in steps of 20 db. This provides measuring ranges with full scale deflection on the instrument of from 100 microvolts to 1000 volts. When the switch marked "Input Switch", below the jack, is in position "Direct", the input jack is connected directly to the attenuator through a capacitor which provides insulation against d.c. voltages, and the input impedance here is about 2 megohms. When the switch is in position "Vol. Control" the jack is connected via a blocking capacitor to a potentiometer, marked "Volume Control", of 1 megohm, the slider of which runs to the attenuator. The input impedance is approximately 0.67 to 1 megohm.

An amplifier stage with aperiodic resistance-coupling follows the attenuator. The cathode circuit of the amplifier tube contains a variable resistor which is used to adjust the amplification of the instrument and is operated by a screwdriver inserted through a hole in the front panel below "Voltage Range". For adjustment purposes the voltage range switch is put at "Ref" and the apparatus will then generate a 50 or 60 c/s a.c. control voltage which is made practically independent of the line voltage by means of a current regulator tube.

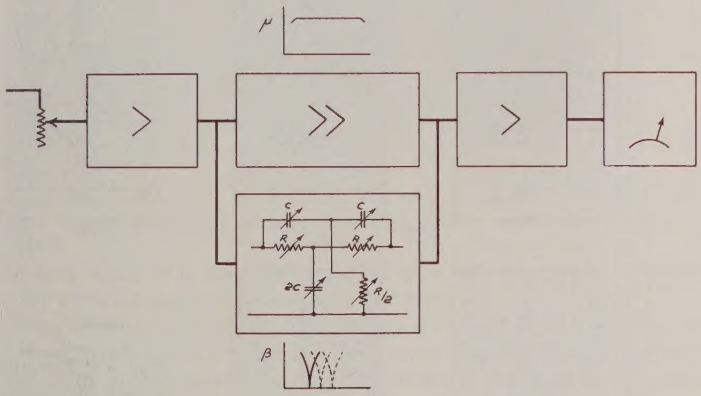


Fig. 3. Block diagram of Analyzer type 2105.

The plate circuit of the first tube is coupled to the selective section of the instrument, comprising two resistance-coupled stages. From the output circuit of the last tube a feedback voltage is applied to the cathode circuit of the first tube through a parallel-T-section filter. The T-section network rejects a single frequency at which, consequently, the amplification reaches its maximum value while being reduced at all other frequencies by the negative feedback. The rejection frequency can be varied continuously within about one octave by means of 3 ganged potentiometers inserted in the T-network, "Tuning", while the octaves are selected by stepwise variation of the capacitors of the T-network, "Frequency Range".

The control knob of the potentiometers is coupled to the double pointer on the illuminated main scale where the frequencies to which the Analyzer is set can be read directly on 8 individually calibrated scales. Changing between the different scales marked 1—8 and the corresponding frequency range is made by the control marked "Frequency Range" which changes the capacitors in the T-network. Due to the large effective scale length, the reading accuracy of the frequencies is somewhat greater than the accuracy of the apparatus itself. We can, however, only guarantee a long term stability of $\pm$ 1 %.

The selectivity is variable in 5 steps by means of an attenuator "Octave Selectivity" which controls the amount of feedback. The different positions are marked 20 db, 25 db, 30 db, 35 db, and Max., corresponding roughly to the attenuation of any given frequency when the Analyzer is tuned one octave off

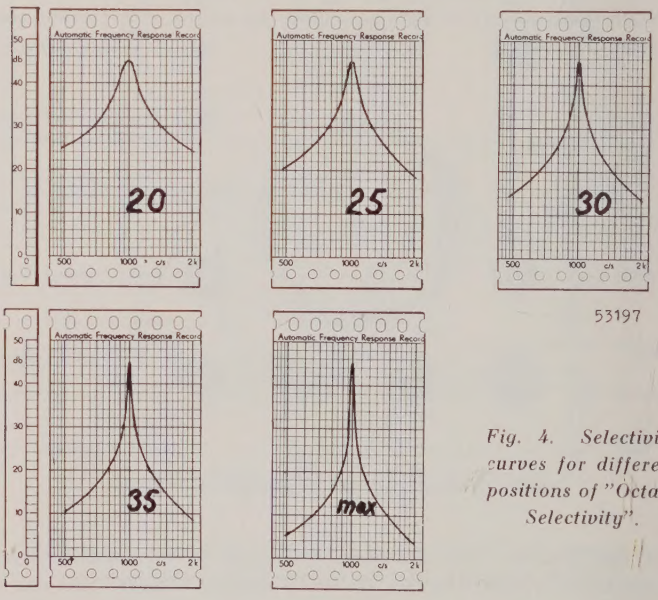


Fig. 4. Selectivity curves for different positions of "Octave Selectivity".

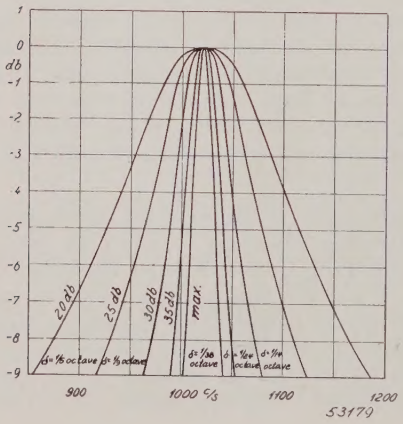


Fig. 5. The tops of the different selectivity curves recorded with extended frequency scale and 10 db potentiometer.

that frequency. The positions 30 db and 35 db are the ones most commonly used. The selectivity in position Max. is approx. 40 db, and since the accuracy here is slightly lower than in the other selectivity positions, position Max. should

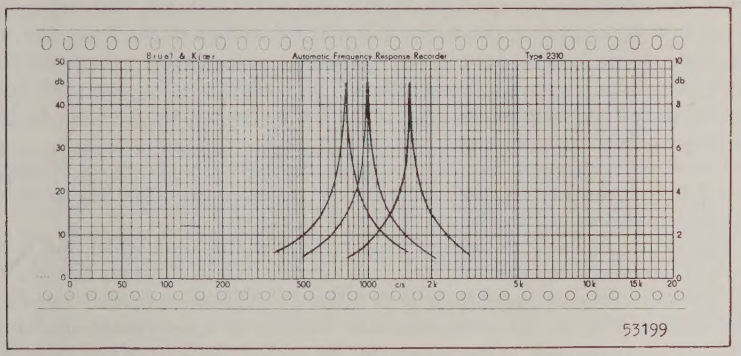


Fig. 6. Slight variations in selectivity with tuning within one octave.

be used only when it is specially wished. Fig. 4 shows a set of selectivity curves for different positions of "Octave Selectivity".

The form of the top of the selectivity curves is of interest, and therefore the tops of the different curves are shown in fig. 5 recorded with extended frequency scale and 10 db potentiometer. The 3 db bandwidth is indicated on the curves as a fraction of the octave.

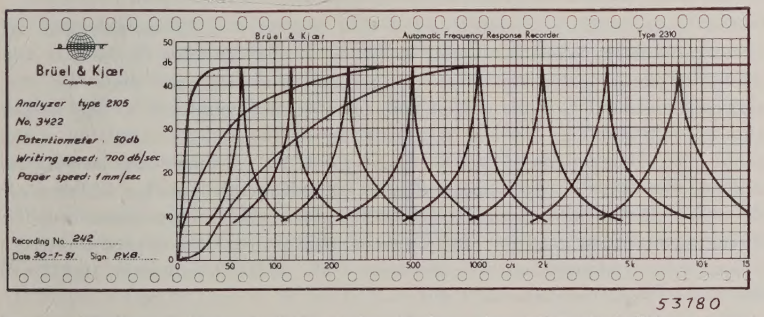


Fig. 7. Frequency characteristic of the Analyzer No. 3422 with different positions of "Frequency Range": "Lin.", "60—130 phons", "30—60 phons". Ranges 1 to 8 set on the frequencies 63—125—250—500—1000—2000—4000—8000 and 12000 c/. The curves are made by forming the recording paper on Recorder 2304 in a loop, and then by this method, scanning the frequency range several times. The irregularities in the lower branch of the selectivity curves for the two lowest frequency ranges are due to a too fast speed of scanning for this low frequency, where the filter has a relatively long time constant.

As a result of the principle employed, the amplification is independent of octave adjustment. However, a slight unbalance in the T-network may cause small variations though they fall within about 1 db. They are also apparent when the selectivity is regulated. Within the octave selected, too, variations of up to 1 db may occur, due to the fact that the loading of the T-network on the plate circuit is dependent on the adjustment of the tuning potentiometers.

For the same reason the bandwidth will vary slightly within the individual octave while remaining at the same value for corresponding positions in the different octaves.

This effect is shown in fig. 6 by recording the selectivity curves for different tuned frequencies of 775, 1000 and 1580 c/s. It can be seen that the curve at 1580 c/s is slightly more selective than that at 775 c/s.

The switch marked "Frequency Range" has 3 positions in which the feedback is cut off. In one position "Lin", the amplification is constant to within 1 db over the frequency range from 30 to 15,000 c/s, while the frequency response characteristics in the other two positions conform to international standards of noise measurements in the ranges 30—60 phons (curve A of the American standard ASA Z 24.3) and 60—130 phons (ASA curve B) with the tolerances prescribed by the standards. Fig. 7 shows a set of frequency characteristics for different positions of "Frequency Range".

The output tube following the selective section drives a rectifier instrument with a logarithmic magnetic field distribution, so that the scale is approximately logarithmic. In order to obtain a correct addition of a complex voltage with many pronounced peaks, the output stage has a saturation level approximately 10 db above the full deflection of the instrument.

The Analyzer has a screened output jack connected to the output stage via an output switch. When the switch is in the "Direct" position the jack is connected to the anode circuit of the output tube and full scale deflection corresponds to about 10 volts output voltage. The load connected to this output should be $> 50\ k\Omega$ in case one wants to rely on the meter's indication at the same time. Turning the switch to "Level Recorder" connects the jack to the cathode circuit with a full scale voltage of 3 volts, corresponding to full scale deflection of the Level Recorder type 2304 with a 50 db input potentiometer. This output can be used too with loads $< 50\ k\Omega$ when it is wanted to have a proper meter indication at the same time. Only with loads down to 10 $k\Omega$ will the meter show an increase of 1 db.

It is possible to record over a range up to 45 db for full scale deflection on the meter. Beyond this, the 10 db above the full deflection may be used, making certain that the addition is correct when complex voltages are recorded.

In addition to the usual voltage input the apparatus is provided with a special 7-pole input jack "Condenser Microphone", intended for connection with a condenser microphone with cathode follower, for example our Condenser Microphone type 4111, or the Artificial Ear type 4109. All voltages, both polarization voltage for microphones and H.T. voltages for the cathode follower

tube, are taken from a built-in rectifier in the apparatus. The polarizing voltage just after the stabilizer tube is led to an extra output terminal called "Polarization Voltage", placed just under the fuse. It is here possible and very convenient to measure the polarizing voltage by using an instrument with a current drain of max. 50 μa.

The Analyzer can be operated from an a.c. power source supplying 115, 127, 150 or 220 volts. The frequency is not critical but ought to be within 40—200 c/s. Plate and screen grid voltages for the pre-amplifier tubes are stabilized, and to keep the hum level at a low value the first two tubes are heated with d.c. from a selenium rectifier. The power consumption is about 45 watts.

Selection of the proper operating voltage is made with the voltage selector on the rear plate of the instrument, which is operated with a screwdriver. The line voltage selected is shown by an indicator disc coupled with the selector.

If it is desired to operate the Analyzer from a d.c. line or an accumulator, it will be necessary to use a vibrator or a rotary converter capable of supplying 115, 127, 150 or 220 volts a.c.

Instructions for Use

Adjustment.

Adjust the instrument to the proper line voltage, switch on, and the scale will be illuminated. After 2 or 3 minutes place the voltage range switch at "Ref" and the frequency range switch at "Lin.". Turn the adjustment potentiometer below the "Voltage Range" switch with a screwdriver until the meter pointer is just at the red line on the scale.

Voltage measurement.

Apply the voltage to be measured to the input jack with the switch in position "Direct" and set the frequency range switch at "Lin". The voltage is read on the meter's volt scale in conjunction with the voltage range switch which indicates full-scale-deflection. The instrument is proof against overloads. The voltage can also be read in db above 1 volt. The db scale on the meter is used and the reading is simply added to the db indication on the selected position for "Voltage Range".

For voltages below approximately 10 microvolts, tube and input circuit hiss make it necessary to use selective amplification, frequency range switch and tuning potentiometers being set to the frequency of the voltage under measurement. The degree of selectivity chosen should be as dictated by the measurement in question. The same procedure should be followed if the voltage to be measured contains some other component, such as a hum voltage.

Frequency Analysis.

After selection of the required selectivity (minimum is 20, maximum is about 40 db for one octave off the selected frequency) the desired range should be traversed with the frequency range switch and the tuning potentiometers. At the same time the voltage readings should be noted. The accuracy mentioned above is valid for an octave damping of 20 -35 db. The 40 db selectivity gives a slightly inferior accuracy and should be used only when necessary.

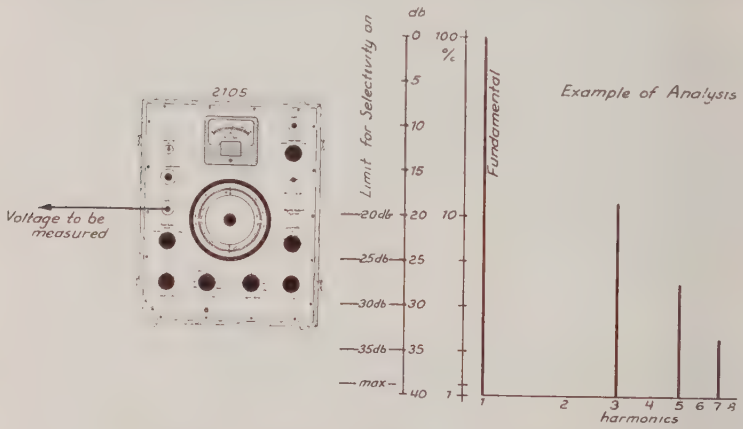


Fig. 8. Example of analysis on a power line.

Fig. 8 gives an example of an analysis and an indication of the smallest harmonic which can be measured with the different degrees of selectivity.

If it is required to analyze a fundamental and a number of harmonics it may be convenient to have the harmonics measured as percentages of the amplitude of the fundamental. For this purpose the instrument should first be tuned to the fundamental frequency, and a maximum deflection produced on the meter, the input switch being set at "Vol. Control", and the amount of deflection adjusted with the volume control. The instrument should now be tuned to the harmonic, the percentage strength of which can be read on the meter scale, full scale deflection being 100 %. The range of 0 10 % is obtained by reducing the damping by 20 db with the voltage range switch.

Applications

Distortion measurement on nearly pure tones.

If it is wished to examine respectively the effect of distortion and harmonics on nearly pure tones, Analyzer 2105 should be used in conjunction with Block-

ing Network 1602. The apparatus is set up as shown in fig. 9, where measurements are shown being taken on Beat-Frequency Oscillator 1012. Blocking Network 1602 is adjusted to damp a single frequency very strongly, while allowing all the other frequencies to pass through the filter. Measurements are made by first setting filter 1602 to its linear range, then adjusting the Analyzer's sensitivity so as to give full deflection for the frequency in question. The Analyzer can either be switched to its linear range, or selectively tuned to the fundamental frequency. The filter is then tuned so that the deflection on the Analyzer becomes minimum, i.e., the basic frequency is completely damped out. Analysis of the harmonics can then be undertaken in the normal way, and in practice it is possible to measure distortion components right down to 0.01 %. To obtain the correct amplitude relations with frequencies which lie below the fundamental frequency, for example, various hum components, filter 1602's frequency characteristic must be used for correction. The correction of frequencies which lie above the fundamental frequency is not necessary. The total distortion can be calculated by adding the effects of the various components, but it can also be obtained direct as a minimum deflection on the Analyzer, when set to the linear response after the filter has been adjusted to give minimum.

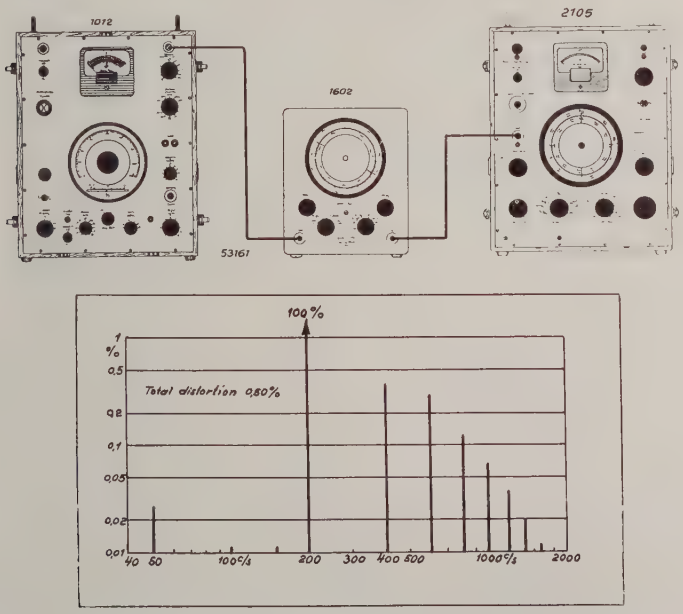


Fig. 9. Distortion measurements on BFO type 1012 No. 3425. Frequency 200 c/s. Output voltage 10 V. Total distortion measured direct 0.49 %. Calculated from the measured spectrogram 0.50 %. Hum component 0.03 %.

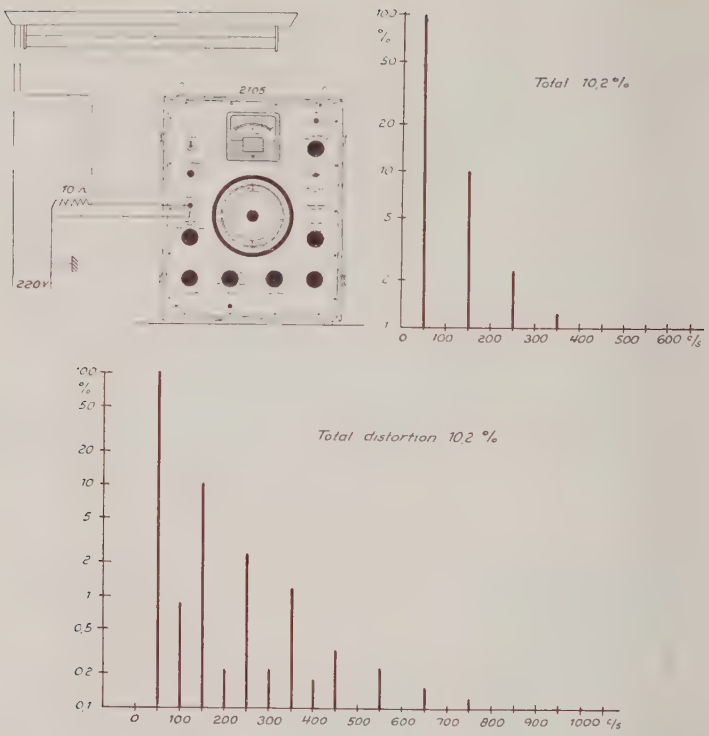


Fig. 10. Analysis of the current in a fluorescent tube. Above: Spectrogram with 2105 alone. Below: Analysis with the combination 1602 + 2105.

Measurement of current distortion.

Fig. 10 shows an example of how the waveform of current in a fluorescent tube can be analyzed. A quite small resistance, for example, 10 ohms, is put in series with the fluorescent tube, and the voltage drop across this resistance is lead to the Analyzer, where the current can be analyzed.

As shown on the diagram to the right of the figure, quite large components of 150 c/s, 250 c/s and 350 c/s are measured. Beyond this the Analyzer alone is unable to measure more components, as they all lie close together within 1 % or less of the amplitude of the power line frequency. The total distortion can either be measured directly or calculated as the r.m.s. value obtained from the measured spectrogram. By using Filter 1602 in front of the Analyzer, cutting out the fundamental 50 c/s or 60 c/s frequency, it is possible to get a more detailed picture, as shown in the spectrogram under the figure. Here it is

possible to measure a part of the even components, as well as uneven components up to 750 c/s, going down to approximately 1 % of the 150 c/s component.

Measurement of light modulation.

A sign of quality for most fluorescent lamps is that the light should vary as little as possible during the alternating current period. A simple measurement of a fluorescent lamp's degree of light modulation can easily be carried out, by means of Analyzer 2105 and a photo-electric cell. The method of measurement is as shown in fig. 11. The photo-electric cell, which is a selenium cell, should preferably work short-circuited, and is therefore loaded with a resistance of 150 ohms, which can be conveniently the shunt of a milliammeter, so that the current from the photo-electric cell can be read directly in ma. The Analyzer is coupled across the resistance, so that the a.c. components can be measured. The total luminous flux from the fluorescent lamp is proportional to the d.c. voltage measured across the shunt: in the example illustrated, 114 mv. It can be seen on the spectrogram that the 100 c/s component is large and similarly the 200 c/s component is relatively strong. The even multiples of 50 c/s are all stronger than the uneven multiples.

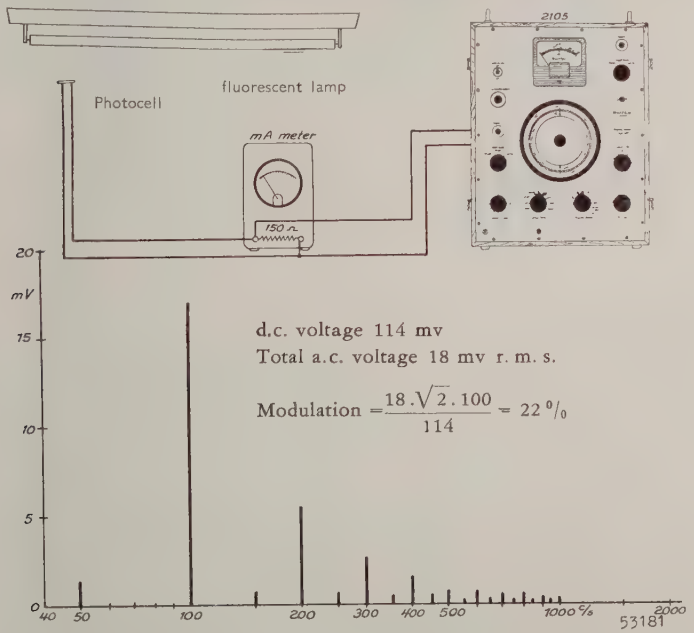


Fig. 11. Measurements of the light modulation of a fluorescent lamp.

By adding the r.m.s. effects of the different components it will be found that the fluctuating light component corresponds to 18 mV. The light is, therefore, modulated 22 %. This method is both cheap and extremely simple, and can be used to advantage in many cases.

Analyzer 2105 as bridge indicator.

When making bridge measurements in the audio-frequency range it is a great advantage to have a reliable and selective instrument in the bridge network. The only requirement the bridge must satisfy is that the one diagonal point can be earthed, as shown in fig. 12. This requires the bridge to be supplied from the Beat-Frequency Oscillator via a well shielded transformer, the signal generator often being earthed at one pole. When making bridge measurements the Analyzer's selectivity and great sensitivity can both be made use of. Further the decibel scale incorporated in the instrument scale will often be of use if it is desired to measure the goodness of the different components placed in the bridge.

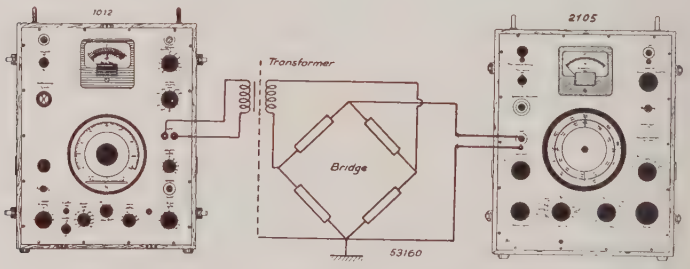


Fig. 12. The Analyzer used as bridge indicator.

Vibration measurements and analyses.

Using our Vibration Pick-up 4303 or 4304 and our Integration Network 1605 or 1604, vibrations in buildings, machinery, ships etc. can be measured and analyzed. Acceleration-, velocity- and deflection-amplitudes can be measured directly in C.G.S. units. The network 1605 or 1604 can be switched for connecting 3 different vibration pick-ups marked X, Y and Z. Another knob switches the network for integration for acceleration-, velocity- and deflection-measurements. The vibration pick-ups are piezo-electric pick-ups with a sensitivity for type 4303 of about 80 mv per 1000 cm/sec^2, and for type 4304 about 10 mv per 1000 cm/sec^2. The pick-ups type 4303 can be used up to 1600 c/s, and they have a basic resonance frequency at about 2200 c/s. At this frequency the sensitivity is increased approximately 15 db. Type 4304 can be used up to 5000 c/s and has a basic resonance frequency at 6500—7000 c/s. The lower frequency limit for the pick-ups in combination with Analyzer 2105 is 16 c/s for type 4303 and

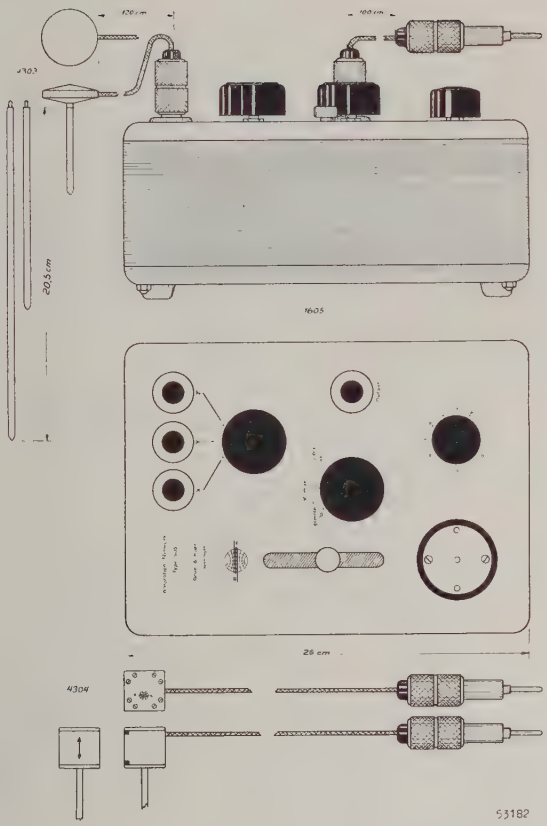


Fig. 13. Dimensions and controls for Vibration Pick-up 4303 and 4304 and Integration Network 1605.

27 c/s for 4304. Fig. 13 shows a drawing of Vibration Pick-up 4303 and 4304 and Integration Network 1605.

When measuring velocity-amplitudes instead of acceleration-amplitudes the filter's lowest control is placed in the middle position "v", in which case the acceleration is integrated with respect to time, so that the filter's output voltage becomes proportional to the velocity of the vibration. It is only necessary to read the output voltage in mv on the Analyzer and multiply by the conversion factor shown on the filter. The velocity-amplitude is then immediately given in cm/sec. In position "a" deflection-amplitudes are obtained, as the integration is carried

out twice. With each integration a certain degree of accuracy is lost, and it is therefore recommended that work be carried out mainly with acceleration and velocity amplitudes, and that deflection-amplitudes be seldom used. In any case there is seldom use for deflection-amplitudes, as the forces to which various objects are subjected are directly proportional to the accelerations, and as can be seen from fig. 14., the "irritation effects" which vibrations have on people are in the main proportional to their velocity-amplitudes.

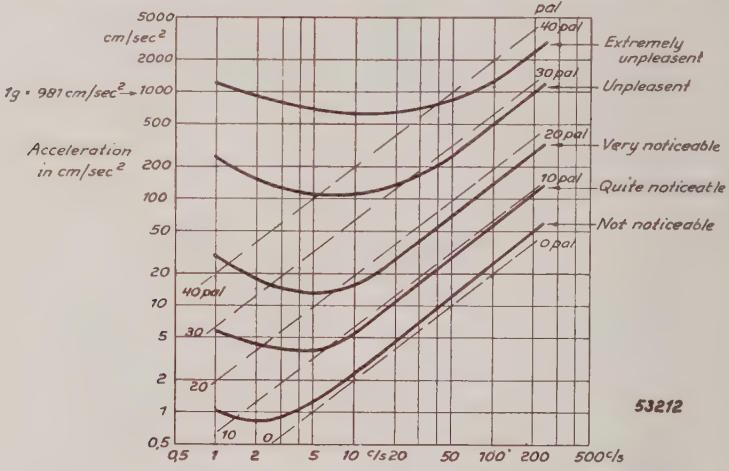


Fig. 14. The "irritation effects" of vibration on the human organism.

The effect of vibrations on the human organism is shown in fig. 14., where the curves set out show the relationship between the acceleration and frequency of vibrations and the degree to which they are noticed by the organism. The curves are an average of results of measurements on both sitting and standing persons, in which only sinusoidal vibrations were used.

It will be noted that with low frequencies the human judgement of the strength of vibrations is mainly dependent on and proportional to their velocity. This has given rise to the suggestion of a unit, the "pal" as a measure of the strength of vibrations. 0 pal corresponds to that vibration velocity which a man can just experience. "pal"units are defined as:

$$\text{Strength of vibration in pals} = 20 \log \frac{u}{u_0},$$

where u is the r. m. s. value of the vibration's velocity and u_0 is a reference level $\mathbf{u_0} = 0.0312$ cm/sec.

The "pal" scale thus corresponds to the normal decibel scale with a reference value of 0.0312 cm/sec. As can be seen from fig. 14. the "pal" scale corresponds rather poorly with the human power of perception for frequencies lower than 20—50 c/s. In practice, therefore, it is correct to use the continuous black curve.

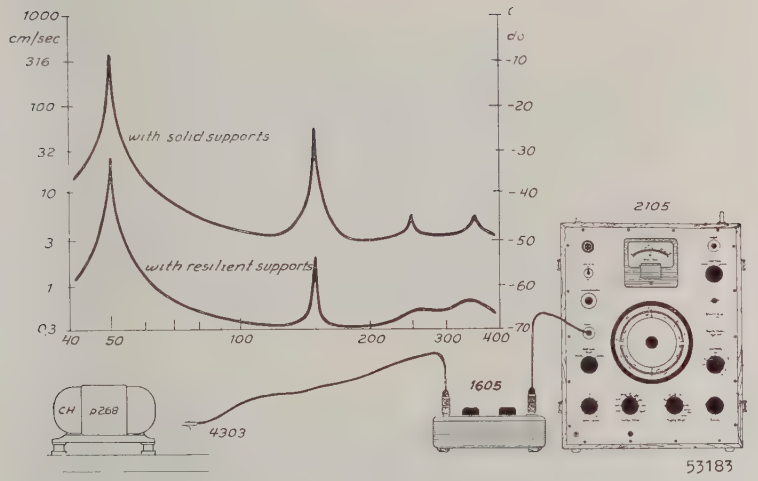


Fig. 15.

As an example, fig. 15 shows a measurement from a rotary generator's suspension with vibration absorbers. An analysis of the acceleration in the floor is first shown, with the machine set up on wooden blocks instead of spring

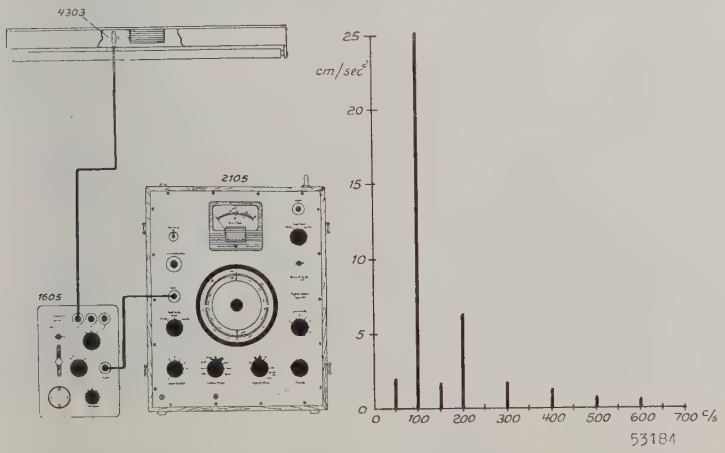


Fig. 16. Measurements of vibration amplitudes on a ballast for a fluorescent lamp.

vibration absorbers (the upper curve). Powerful vibrations on 50 c/s and 150 c/s are seen. Underneath, the same curve is shown after the machine has been set up on vibration absorbers. The damping is greatest with the higher frequencies, apart from the frequencies between 300 and 400 c/s, where a certain amount of energy is transmitted through the steel springs. As the readings on fig. 14 show, the machine's vibrations are reduced from "very unpleasant" (31 pal) to "quite noticeable" (12 pal) as a result of the installation of vibration absorbers.

Fig. 16 shows the results of some measurements on the ballast in a fluorescent lamp mounting. These iron coils often give rise to a humming noise, so that it is of interest to measure the actual vibrations in the coil and mounting. A typical result is seen on the right hand side of the figure, where the most powerful amplitudes are at 100 c/s and multiples of this.

Condenser Microphone type 4111.

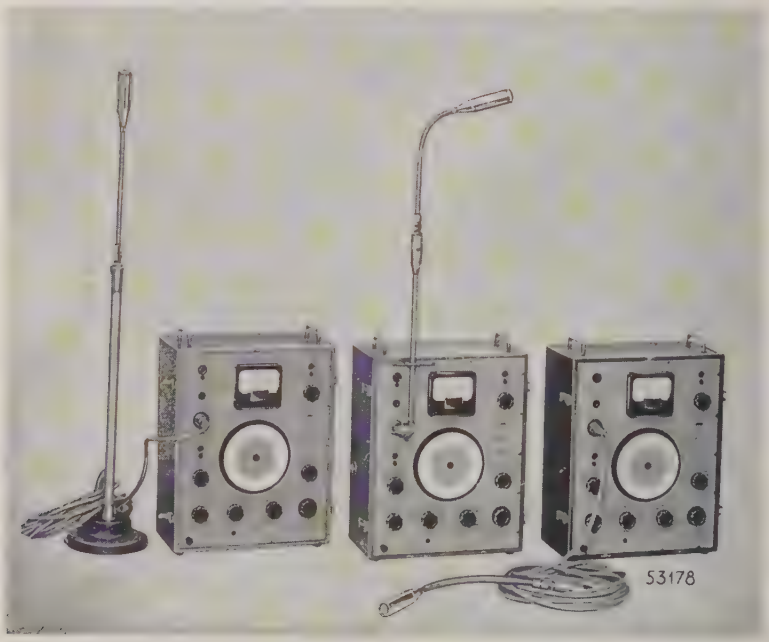


Fig. 17. Photograph of the Condenser Microphone type 4111 connected to the Analyzer in three different ways.
left: connection through the Microphone Stand 4112
middle: direct connection through the Extension Rod 4115
right: connection through the Extension Cable 4114.

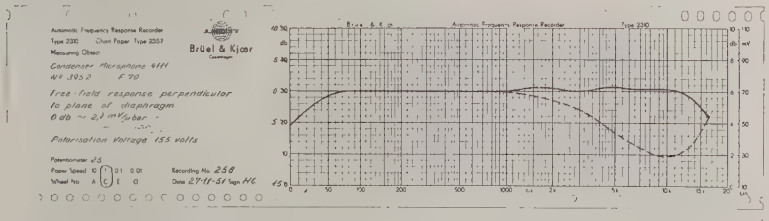
The Condenser Microphone type 4111 can be connected to the Analyzer in three ways:

1. The Condenser Microphone can be mounted directly on the Analyzer 2105 with its special Extension Rod type 4115. The small extra accessory type 4116 fastened on top of the Analyzer's front plate, is used for guiding the Extension Rod type 4115 upwards. Care must be taken before placing the microphone in the socket of the Rod in order not to prevent the 7-pin plug being twisted.
2. The microphone can be fastened on the Stand type 4112 which by means of its 10 m cable can be connected to the Analyzer.
3. The Condenser Microphone 4111 can be connected through the 10 m Extension Cable type 4114 to the Analyzer.

When the Condenser Microphone is not being used is should be kept together with the Extension Rod in a case, and the greatest care should be taken each time it is taken out and mounted on the Analyzer. Particular attention must be paid to prevent the protective screen receiving any severe blows, which might bend the screen down upon the sensitive membrane.

An adjustment curve will be found at the back of the instructions for use of the Condenser Microphone, with drawings of the individually calibrated sensitivity curves. The Condenser Microphone's serial number and cartridge number are also given, as well as the sensitivity expressed in mv/μbar for a specified polarization voltage.

This sensitivity corresponds to the output voltage from the built-in cathode follower, which results initially from the voltage as generated by the cartridge itself after 2 attenuations. First there is a loss of sensitivity owing to the input capacity of the cathode follower. This capacity (C^f) is about 10—15 pF and the cartridge capacity (Cc) is around 50 pF. The added capacity of the cathode follower will decrease the sensitivity by the ratio of C_c to $C_c + C_f$. The sensitivity loss owing to this capacity in the cathode follower is around 2—2½ db. Secondly, the cathode follower will cause the drop $\mu/\mu+1$ where μ represents the amplification factor of the tube; this drop amounts to 0,5 1 db.


Automatic Frequency Response Recorder
Type 2305 Chart Paper Type 2353
Measuring Object
Condenser Microphone 4111
No 3952 F 70
Free-field response perpendicular to plane of diaphragm
0 db ~ 2,1 mV/µbar
Polarisation Voltage 155 volts
Brüel & Kjær
Recording No. 258
Date 27-IV-51 Sign. HC
Automatic Frequency Response Recorder Type 2310

53786

Fig. 18. Free field response curve for Condenser Microphone type 4111, serial No. 3952, cartridge No. F. 70. Free field response for incident waves perpendicular to the diaphragm. 0 db corresponds to 2.1 mv/µbar. Polarization voltage = 155 v. Dotted curve: free field correction. The correction is the difference between the zero-line and the dotted curve.

If the microphone is attached to an Analyzer the polarization of which is different from that with which the microphone has been measured, a correction for the difference in polarization voltage must be made, the sensitivity being directly proportional to the polarization voltage. The polarization voltage given by the Analyzer type 2105 should be measured with a precision voltmeter with max. 50 μa current consumption. When this is done once for all, the polarization voltage should be marked on the Condenser Microphone's sensitivity curve, and the Condenser Microphone's absolute sensitivity should be corrected to the right polarization voltage. If the Analyzer's voltage regulator tube V6 is replaced for any reason the polarization voltage must once again be measured.

Measurements of Sound Pressure level.

With precision measurements of sound pressure, care must be taken that the microphone is placed in the sound field remote from any disturbing reflecting objects, and the microphone membrane should be directed towards the sound source, as its adjustment curve is based on the sound waves striking the membrane perpendicularly. If it is believed that the Analyzer itself has a disturbing effect on the sound field, it is recommended to use the Microphone Stand type 4112. If a further separation between the Analyzer and the microphone is desired, the Extension Cable 4114, with a length of 10 metres, can be introduced.

When the Analyzer's voltage sensitivity is adjusted as previously described, as precisely as possible, the measurements can begin. If pure tones are being measured, for example those from a loudspeaker driven by a beat-frequency oscillator, the linear frequency characteristic can be used, and the voltage indicated as a function of the frequency read off and noted. If the sound pressure being measured is very small, so that undesired noise disturbs the measurement, it is recommended that the selective ranges on the Analyzer be used. The latter procedure is naturally also required with every frequency analysis. When the measured results are finally available in the form of voltages, measured in mv, these should be converted by means of the microphone's sensitivity curve to sound pressures in μbars or in db above 1 μbar. 1 μbar = 1 dyne/cm^2). As the Analyzer scale is graduated to show the r. m. s. values of the voltages, the sound pressures obtained are also r. m. s.

To simplify the conversion from voltage to sound pressure the following table 1 should be filled out with the multiplication factors for the various standard frequencies. The multiplication factors are the reciprocal of the sensitivity, valid for the particular polarization voltage of the Analyzer 2105 employed and are given in μbar/mv.

Standard Frequency c/s	Multiplication Factor μbar/mv	Standard Frequency c/s	Multiplication Factor μbar/mv
20		630	
25		800	
32		1000	
40		1250	
50		1600	
63		2000	
80		2500	
100		3150	
125		4000	
160		5000	
200		6300	
250		8000	
315		10000	
400		12500	
500		16000	

Table 1.

This table is effective for Analyzer type 2105 No. with Condenser Microphone type 4111 No . 1) Check Analyzer's voltage sensitivity. 2) Measure with the sound waves striking the microphone membrane perpendicularly. 3) Multiply the voltages read in mv by the above multiplication factors. The sound pressure will then be obtained in μbar = dyne/cm^2.

In case less precise sound level measurements are made with other types of microphones (moving-coil, crystal etc.) with given average sensitivity or even with complete free-field frequency response curve, the same procedure can be followed. If the sound pressure level in db above the standardized reference value $2 \cdot 10^{-4}$ dynes/cm^2 is wanted and the microphone sensitivity S is given in db re 1 volt/dyne/cm^2, it will be easiest to read off the db scales the measured voltage A in db re 1 volt, from which follows the sound pressure level:

$$\text{S.P.L.} = \text{A} - \text{S} + 74 \text{ db re } 2 \cdot 10^{-4} \text{ dynes/cm}^2$$

Noise Measurements.

The determination of absolute sound pressure expressed in μbar is useful for many physical investigations, but the sound pressure at different frequencies does not however immediately give an indication of the human ear's perception of the sounds' strength, as the ear is less sensitive to sounds of both low and particularly high frequency in comparison with the middle frequencies. This variation of sensitivity with frequency is very complicated as the absolute sound level also plays an important role. Sounds that seem to the ear to be equally loud are said to have the same subjective strength or loudness. Loudness is expressed in phons. In determining the loudness, the sound is compared with a tone of 1000 c/s whose physical energy is adjusted so that sound and 1000 c/s tone appear to the ear to be of equal strength.

The loudness, expressed in phons, of the sound in question is then equal to the physical intensity of the 1000 c/s tone expressed in db above 2×10^{-4} μbars, or what is the same, in db above 10^{-16} watt/cm^2. At 1000 c/s, therefore, phon scale and decibel scale become identical, but at all other frequencies they will be different. Fig. 19 shows the sensitivity curves of the ear. The curves represent averages derived from testing a great number of people.

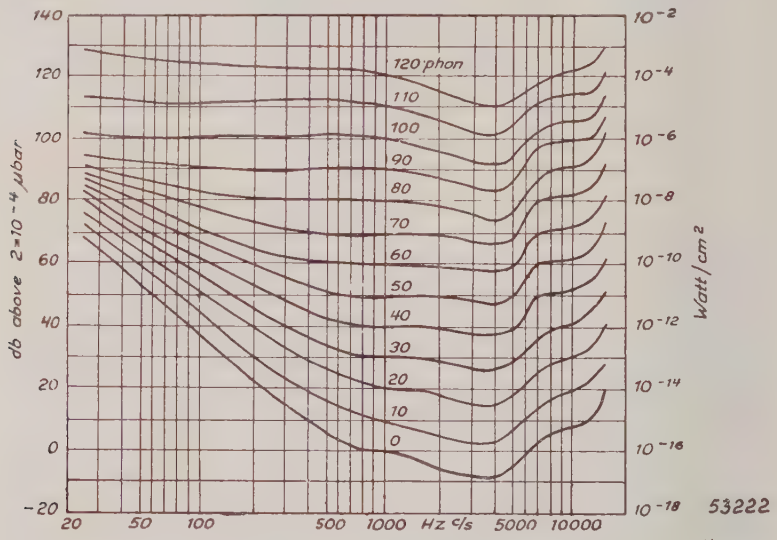


Fig. 19. The sensitivity curves for the human ear (Fletcher & Munson).

In order that a sound-pressure meter should be able to measure the sound level in phons instead of μbar, it is necessary that the meter should have such frequency characteristics that the low and very high frequencies be depressed in a manner corresponding to fig. 19. In practice it is sufficient to have three different characteristics each effective in their own level range. In Europe the characteristics set down in DIN 5045 are used, and in America the slightly divergent standards set down in ASA Z24.3. The various frequency characteristics are drawn in fig. 20 and it will be seen that the deviations are only noticeable for frequencies under 100 c/s, and it is happily the case that the tolerances permitted both for the European and American standards are so great that it is possible to give an instrument frequency characteristics which satisfy both Standards' requirements. The Standards set down also contain requirements for the sound-level meter's dynamic characteristics, frequency addition and overload safety factor. All these requirements are satisfied within the permitted tolerances in Analyzer 2105 when equipped with a Condenser Microphone type 4111. The Analyzer is equipped with 3 frequency characteristics for use

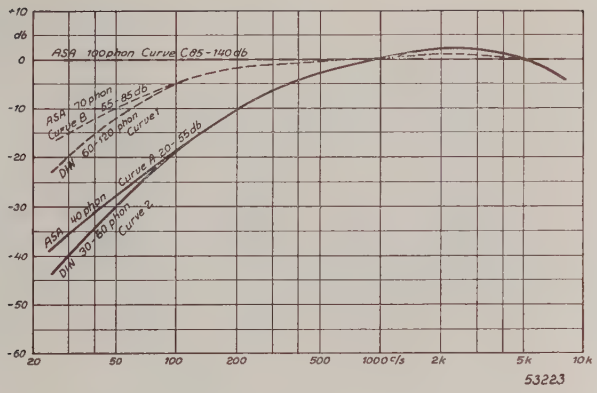


Fig. 20. Frequency characteristics for sound level meters.

in noise measuring. The 3 characteristics are given by the last 3 positions of "Frequency Range", and are marked "Lin.", "60—130 phons" and "30—60 phons". These characteristics are used with the following noise levels, in agreement with the two Standards.

	Frequency Characteristics of Analyzer	Lin	60—130 phons	30—60 phons
American Standard ASA Z.24.3	Characteristic Description	Curve C	Curve B	Curve A
	Characteristic Description	ASA 100 phons	ASA 70 phons	ASA 40 phons
	Range used	85—140 phons	55—85 phons	20—55 phons
European Standard DIN 5045	Characteristic Description	None	Curve 1	Curve 2
	Characteristic Description	None	DIN 60—130	DIN 30—60
	Range used	None	60—130 phons	30—60 phons

Table. 2.

The European Standards also include a characteristic Curve 3, used for noise measurements under 30 phons. As the American Standards measure down to 20 phons with a characteristic which in addition is of flatter extension than DIN 30—60, it is considered best not to complicate the Analyzer with this infrequently used characteristic. The noise measurements themselves are carried out just as described for measurements of sound pressure, but instead of read-

ing off the deflection in mv and converting to sound pressures, the deflection is read off on the instrument's db scale and to this is added the phon value farthest out on "Voltage Range".

It is seen that a reading of 0 db or 1 volt corresponds to 120 phon. Remembering the equality of phon and decibel scale at 1000 c/s and the zero point $2 \cdot 10^{-4}$ μbar, 120 phon means a sound pressure of 200 μbar at this frequency, which consequently can only be measured as a 1 volt deflection on the instrument for a microphone with a sensitivity of 5 mv/μbar. Thus, with the sensitivity of the Analyzer adjusted as usual to the red mark of the instrument scale, no correction will be needed for the total phon reading with noise measurements, using microphones with this reference sensitivity of 5 mv/μbar. Any other microphone sensitivity s mv/μbar will demand the addition of a constant

$$K = 20 \log \frac{5}{s} \quad \text{phons}$$

to the total phon reading.

This correction constant, which amounts for our Condenser Microphones type 4111 to values around 8 phons (e.g. see fig. 18 for a Condenser Microphone 4111 with $s = 2.1$ mv/μbar yielding a K of 7.6 phons), and which should be determined once and for all for a certain combination Analyzer-Microphone, is usually added to the phon reading. With many noise measurements to be made with type 4111 Condenser Microphone, this addition after each measurement can either be simplified or even completely avoided by making use of the instrument's own sensitivity adjustment, which is adjustable by means of the potentiometer below the "Voltage Range" switch from about —3 db (with full negative feedback for the first stage) to + 10 db (with minimum feedback) around the red mark on the instrument's scale. Two methods can therefore be followed:

1) For noise measurements > 30 phons, adjust the Analyzer's sensitivity (10—K) db below the red mark. The noise level will then be:
   Scale reading in db + "Voltage Range"s phon index + 10 phons.
2) For noise measurements < 30 phons adjust the Analyzer's sensitivity K db above the red mark. The noise level will be:
   Scale reading in db + "Voltage Range"s phon index phons.

In order that this last method can be used it is necessary that the microphone's sensitivity is so great that K is not bigger than 8, otherwise the decrease of negative feedback in the Analyzer's amplifier will spoil the frequency response of the instrument and thus make the measurements less precise and cause difficulties with hiss and microphonics.

Registering noise meter.

By connecting our Level Recorder 2304 to the Analyzer noise can be recorded over a longer period of time, as shown in fig. 21. It is often of interest to be able to register the noise in a workshop throughout a whole working day, or traffic noise throughout a day, in order to find out the noisiest periods and get all the maxima recorded.

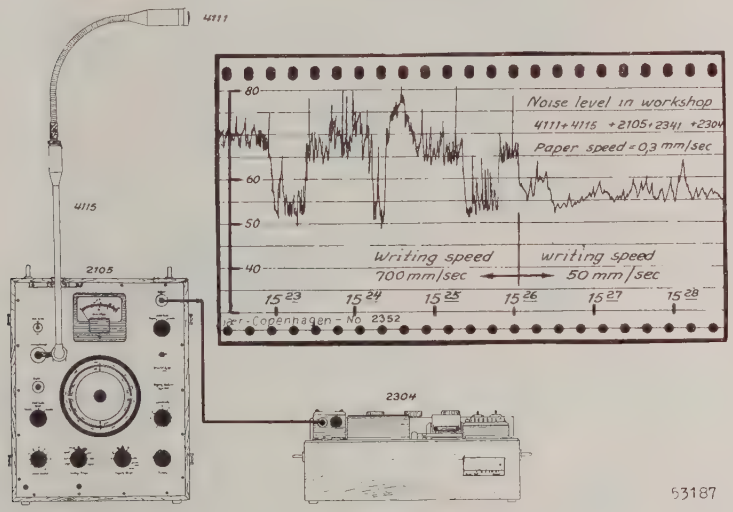


Fig. 21. Recording of noise during longer time.

If a detailed picture is required, it must be recorded with both high writing speed (which can be varied on Recorder 2304 in 9 logarithmic steps between 50 and 1000 db/sec) and high paper speed (which can be varied in 10 logarithmic steps from 0.003 to 100 mm/sec). In this way for example, even the individual hammer blows in a workshop can be recorded. If on the other hand it is wished to obtain average values with greater ease, the recording can be done with lower writing speed and also if desired lower paper speed.

Another important field where recording is necessary is where the noise only persists a very short time, so that the opportunity does not exist to follow its course by reading off an indicating meter. Typical examples are the measuring of noise from passing motorcycles and motor cars, as is shown in fig. 22.

In making these measurements a 50 db potentiometer is normally used on the Level Recorder, and that frequency characteristic which suits the particular noise level in question must be chosen. As seen in fig. 21 and 22 the horizontal lines on the recording paper correspond to round phon figures. This can be achieved easiest by adjusting the Analyzer as explained on p. 24, method 1

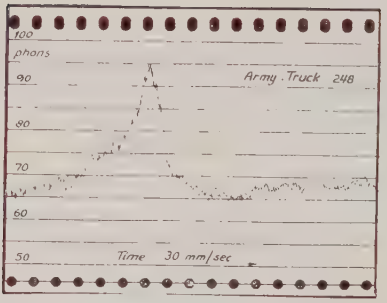


Fig. 22. Record of noise level from a fast passing automobile. Measuring equipment is the same as shown in fig. 20.

and 2. The Analyzer's meter indication is then correct or only 10 phons should be added, and the deflection which the reference voltage gives can thereupon be used to let scale values of the meter and the printed lines on the Level Recorder's recording paper coincide.

Weighted spectrograms.

Almost every time a noise level measurement is taken it is necessary to analyze the frequency composition of the noise. A curve of sound pressure in μbar against the different frequencies cannot be used directly to judge the most disturbing frequency ranges. The spectrograms must first be corrected for the ear's frequency sensitivity by means of the ear-sensitivity curves of fig. 19. When the spectrogram has been corrected in this way it is described as "weighted" with reference to the ear's sensitivity. It is important that the appropriate level-curve be chosen for the calculations.

An example is shown in fig. 23, where the continuous curve shows sound pressure as a function of frequency, for the noise from an electric cash register. The broken line shows the weighted spectrogram, where it will be seen that the low frequencies here become less strongly represented. The calculations are shown in the table.

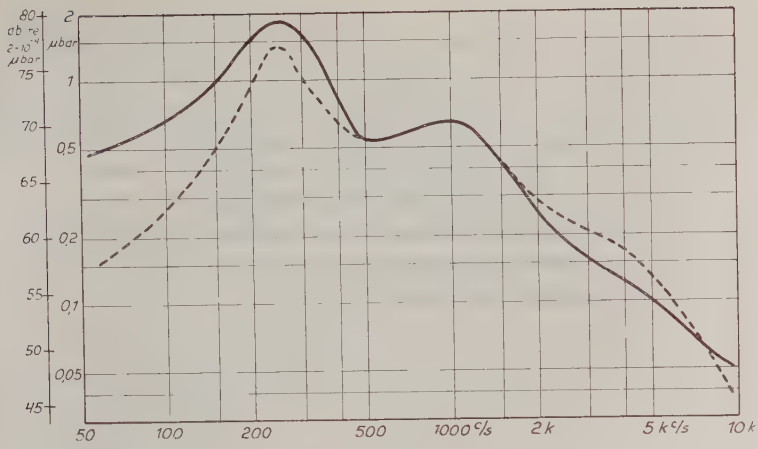


Table. 3. Example of a calculation of a "weighted" spectogram. (solid curve), and the same spectrogram weighted with reference to the sensitivity of the ear (broken curve).

Frequency c/s	63	125	250	500	1000	2000	4000	8000
Measured voltage in mV	0.9	1.4	3.5	1.1	1.3	0.5	0.25	0.11
Sound pressure in μbars without microphone correction	0.47	0.74	1.84	0.58	0.68	0.26	0.13	0.058
Correction for microphone in db	+0.6	0	0	0	0	-0.4	-.04	-.03
Multiply by	1.07	1	1	1	1	0.95	0.95	0.97
Real sound pressure in μbar	0.50	0.74	1.84	0.58	0.68	0.25	0.12	0.056
Correction from Fig. 19. 70 phon curve, in db.	-10	-6	-2	0	0	+1	+3	-1
Weighted sound pressure in μbars	0.16	0.37	1.46	0.58	0.68	0.28	0.17	0.05

Table 3. Example of a calculation of a "weighted" spectrogram.

Measuring acoustic noise from fluorescent lamp mountings

The measuring of noise level and the determination of the acoustic analysis of noise from fluorescent lamp mountings, etc., is difficult, because the level of the noise to be measured is so small, that it is at the limit of the technically possible. To increase the acoustic effect from the mounting, and reduce external

disturbances, it is recommended that the mounting be placed in a special oblique-angled measuring box or a small measuring room with very hard sound-reflecting walls. A room with a volume V of about 2 m^3 and with walls, floor and ceiling constructed of 10 cm concrete, covered internally with smooth and hard tiles, is very suitable. The reverberation time T can easily be brought up to about 2 sec, and with the help of small resonators can be adjusted for constancy over a frequency range of from 60 c/s—500 c/s.

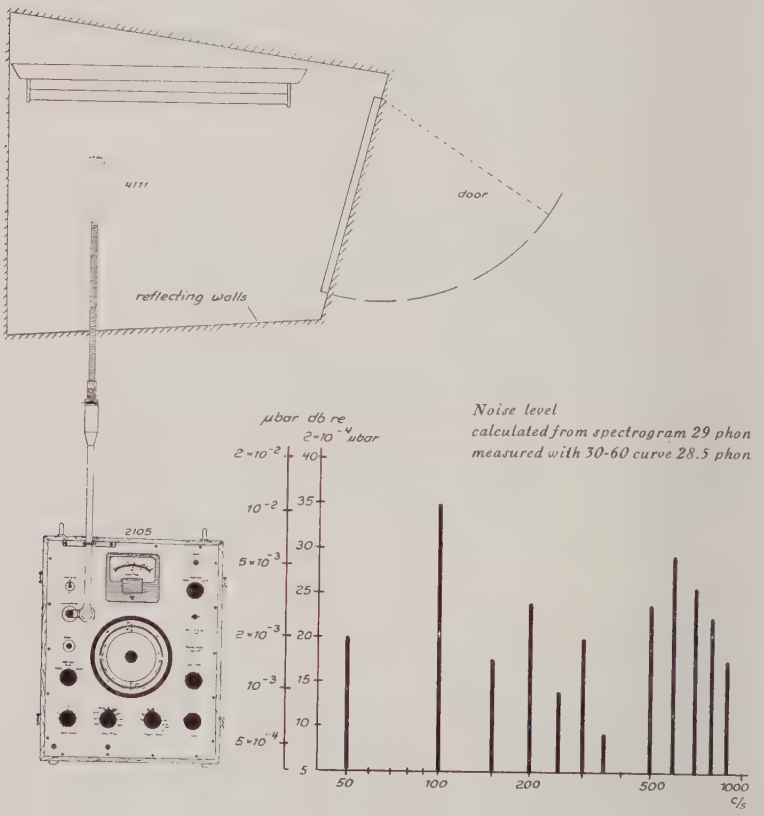


Fig. 29. Measurement of noise level from a mounted fluorescent tube.

With a 2 sec reverberation time the total absorption in the measuring space is

$$\sum \alpha S = A = \frac{0.16V}{T} = 0.16\,m^2$$

The intensity in the room is

$$E = \frac{4N}{c\bar{A}}$$

where N is the total energy radiated from the fluorescent lamp mounting, c is the velocity of sound. A point source of sound with the same radiation intensity placed in a sound-absorbing chamber will at a distance R give an intensity

$$E = \frac{N}{c4\pi R^2}$$

We thus find from the above example that the distance R_0 which gives the same sound level as in the sound reflecting measuring room is

$$Ro = \sqrt{\frac{\bar{A}}{16\pi}} = 0.06\,m$$

As the fluorescent light mounting is of much greater dimensions than this distance, it is not practical to measure in a sound-absorbing chamber at such a small distance and have the various components of the mounting represented. In order to measure in a sound-absorbing chamber the measuring distance must be about 1.2 metres, which reduces the sound pressure being measured to 1/20.

Fig. 24 shows a typical measuring set-up together with the result of an investigation. It will be seen that the measured sound pressures at different frequencies lie between 8 and 35 db above 2.10^{-4} μbars. It will be noted that if the same mounting had been measured in a sound-absorbing room it would have been necessary to measure pressure between —18 and 9 db above 2.10^{-4} μbar which would have been almost impossible because of external disturbances. The noise level in the example shown measures up to 28.5 phons, and a calculation based on the spectrogram's sound pressure gives 29 phons.

Measuring loudspeakers' frequency characteristics.

As shown in fig. 25, the Analyzer can often be used with advantage as a pre-amplifier for Condenser Microphone 4111 in connection with Level Recorder 2304. The example shows the measuring of a loudspeaker's frequency characteristic. The measurement is carried out with a constant current to the loudspeaker, the loudspeaker being fed in series with a small resistance R, whose voltage drop is led to the compressor input of BFO type 1012. In this way the current to the loudspeaker is held constant, independent of variations in frequency and loudspeaker impedance. The measurements are carried out in a sound-absorbing room so that disturbing reflexions are avoided. The Level Recorder type 2304 drives the BFO's frequency scale so that the sound pressure from the loudspeaker is recorded as a function of frequency on the Level Recorder's paper. The Analyzer's linear characteristic is naturally used when recording the frequency characteristic of the loudspeaker. The advantage with this set-up is that at the same time, and with the same arrangement, distortion

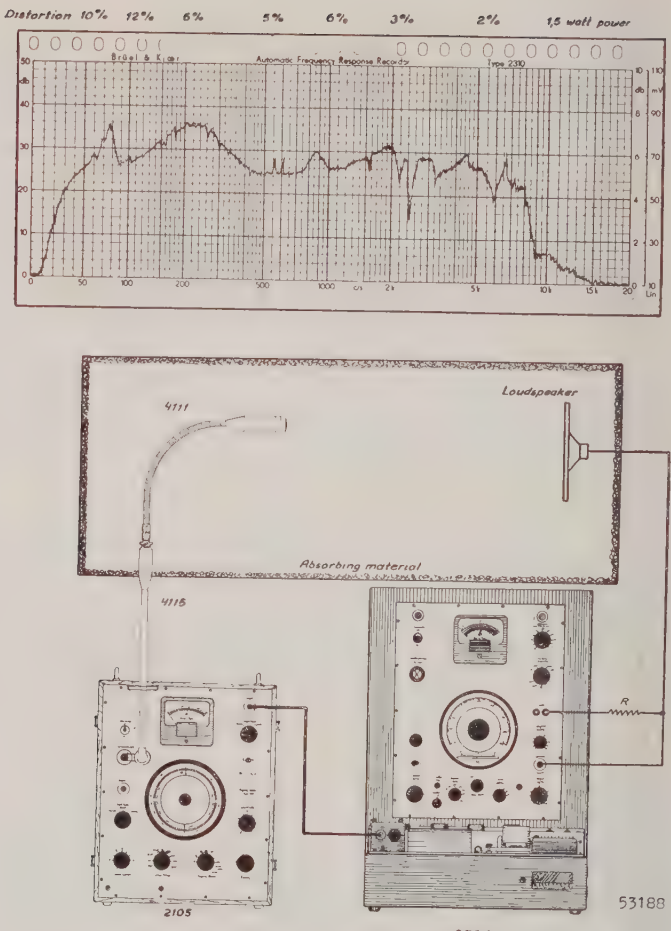


Fig. 25. Measurement of loudspeaker characteristic with constant current.

can be measured, which is important with most loudspeaker measurements. After traversing the frequency characteristic the change over to selective curves can be made and distortion at different pre-selected frequencies measured, as shown at the top of the example.

Control of audiometer.

The Artificial Ear type 4109, consisting of a condenser microphone cartridge and a cathode follower, can be directly connected to the Analyzer. The

necessary voltages for polarization of the microphone cartridge. H.T. and d.c. filament voltage for the cathode follower tube are supplied from the Analyzer. Various couplers constructed according to the American Standard's Association's standard Z24.9—1949 can be attached to the front of the condenser microphone cartridge. The normal 6 cm^3 coupler is used for testing large head-telephones, as for example audiometer telephones and normal telephones.

Fig. 26 shows the measurement of an audiometer's acoustic output. The audiometer's distortion-factor can be checked with the same apparatus. This factor is of great importance with low frequencies where most audiometer telephones often give a strong distortion depending on the intensity. With the

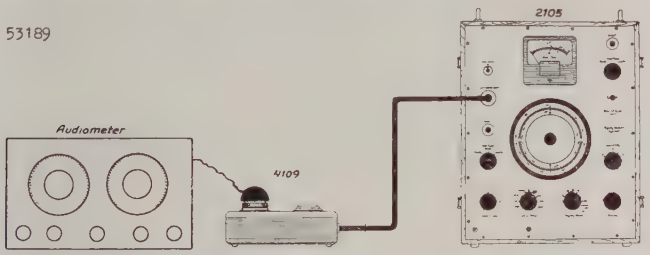


Fig. 26. Complete control of an audiometer.

Analyzer itself the audiometer's attenuator can be checked, by measuring the voltages applied to the telephone. With selective measurements it is possible to check the attenuator right down to the limit of hearing. Similar measurements can be made with all types of telephones. The normal 2 cm^3 coupler is used principally for the small hearing-aid receivers which are held on the external meatus with a special support.

Control of hearing aids.

Fig. 27 shows how a complete measurement of a hearing aid is carried out. The Artificial Ear type 4109 and Analyzer are used as sound receiver. The output from the Analyzer is lead to the Level Recorder type 2304, which records the sound pressure level as a function of the frequency. The Level Recorder drives the BFO type 1012, which by means of a good quality loudspeaker supplies the necessary sound. The measurements take place in a sound-absorbing room whose walls are powerfully absorbing. In order to eliminate irregularities in the loudspeaker's characteristic, and the faults in the sound absorbing room, a normal microphone type 4111 is placed beside the hearing aid, and the voltage from this microphone is fed to the BFO's voltage regulator. The sound pressure is thus automatically held constant at the hearing aid.

A linear amplifier could quite satisfactorily be used for these measurements instead of Analyzer type 2105, but as one of the most important measurements

with the checking of hearing aids is that of the distortion, it is most strongly recommended that the Analyzer be used as amplifier for the Artificial Ear, and after each recording of frequency characteristic include a measurement of distortion of a suitable number of frequencies.

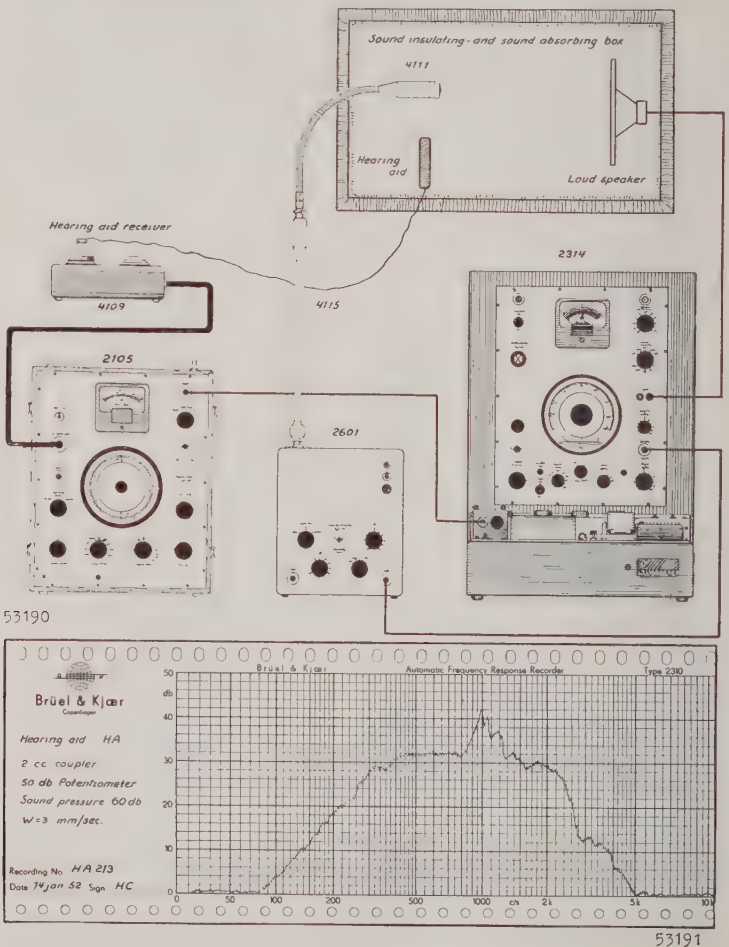


Fig. 27. Complete control of hearing aids.

Measurement of reverberation time.

In measuring reverberation time it is often required to have selective amplification when recording the level with the Level Recorder type 2304. This is

necessary if a gun is used as a sound source instead of a beat frequency oscillator and loudspeaker. The arrangement of the apparatus is shown in fig. 27. One curve is recorded for each shot, and the range of the Analyzer is successively traversed through the whole acoustical frequency range. It is recommended to have at least 3 shots per octave.

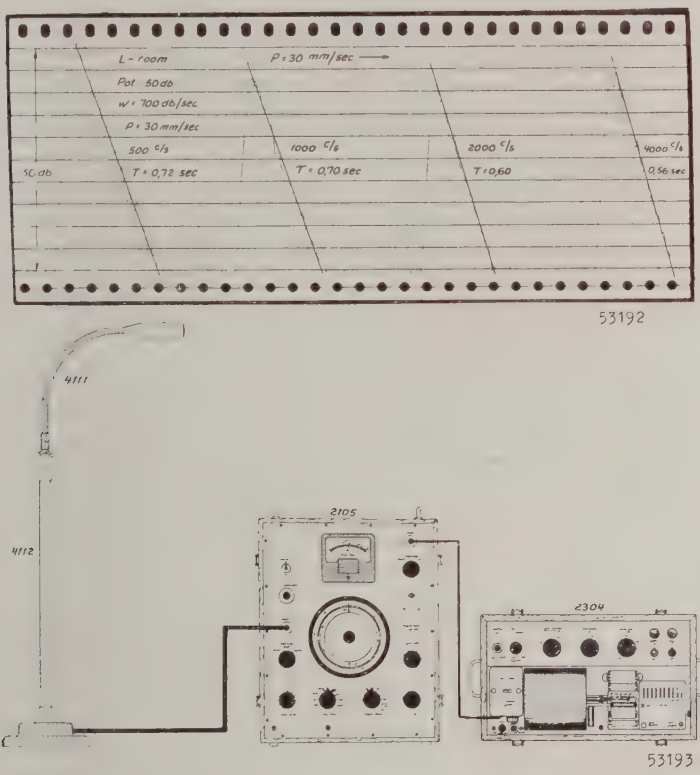


Fig. 28. Measurement of reverberation time.

Insulation measurements of airborne and impact sound with an impact sound generator.

Fig. 29 shows a handy and simple method for the measurements of airborne and inpact sound insulation of walls and floor partitions in buildings.

The air-borne sound insulation of the partition between room 1 and room 2 is measured by producing a high sound level containing almost all acoustical frequencies by placing the impact sound generator on a wooden board which

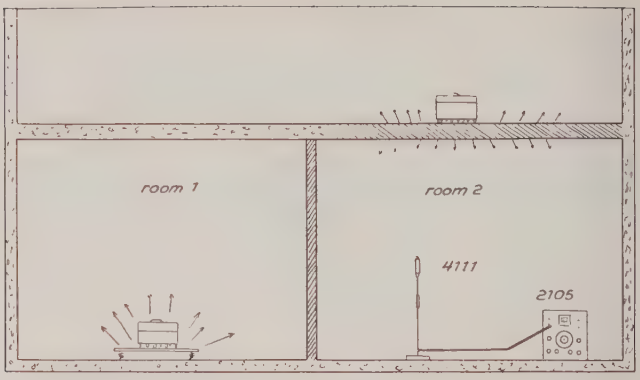


Fig. 29. Simple measurement of sound insulation in buildings.

again is placed on springs, so that the total sound energy from the impact sound generator is radiated as air-borne sound and only a very small amount as impact sound.

With the Analyzer and the Condenser Microphone the sound pressures at different frequencies are first measured in room 1 and then in room 2. From the difference between the two readings the air-borne sound insulation D is found as a function of the frequency, when correction is made for the absorption of the receiver room according to the formula

$$D = 20 \log \frac{P_1}{P_2} + 10 \log \frac{F}{A_2} \text{ db}$$

where F is the area of the wall between room 1 and 2 and A_2 the absorption of the receiver room, both measured in the same units.

The inpact sound insulation is measured in the ordinary way by placing the impact sound generator directly on the floor, measuring the noise level below the floor partitions, and determining the impact sound insulation figure according to the formula

$$I = 129 - L - 10 \log \frac{A_2 m^2}{1\ m^2} \text{ (db')}$$

where L is the noise level in phons, and A_2 the absorption units in m^2 in the receiver room. The constant 129 is determined from the standardized impact sound generator.

Measurement of acoustic absorption coefficient.

With the Standing Wave Apparatus type 4002 the acoustic absorption coefficient of small samples can be measured by inserting them at the end of the measuring tube. See fig. 30.

The apparatus is connected, as shown, with a beat-frequency oscillator, for example type 1012, and the microphone built into the microphone carriage is

connected to the Analyzer. Standing waves are produced in the measuring tube, and the maxima and minima can be measured by moving the microphone carriage. The ratio between the maxima and minima determines the acoustic absorption coefficient of the sample. The Analyzer's indicator meter is equipped with a set of extra scales, from which the absorption coefficient can be read directly.

At the top of the figure can be seen the instrument scale with two ranges, one from 0 to 100 % and the other from 0 to 30 %. The microphone carriage is first placed at a point where the sound pressure is a maximum, then the Analyzer's amplification is adjusted so that the pointer is at full deflection. The microphone carriage is then displaced to a minimum position, and the absorption read in per cent directly from the Analyzer scale graduated 0—100 %. By increasing the amplification 10 times before taking the minimum reading, the absorption coefficient can be read on the scale 0—30 %.

Standing Wave Apparatus type 4002 is equipped with 2 measuring tubes, one with a frequency range covering 95 to 1800 c/s and the other covering 800 –6500 c/s. Acoustic absorption materials whose coefficients range from approximately 2 % to 100 % can be measured with this apparatus.

Measuring the intensity of ultrasonic vibrations with a thermocouple.

With a set-up as shown schematically in fig. 31 it is possible to measure the intensity of ultrasonic vibrations using the selective Analyzer in connection with a very thin and fine thermo-element. The ultrasonic generator must be amplitude modulated with a low frequency, for example the frequency of the power supply. The degree of modulation should always be constant, and lie between 10 and 50 %. It is usually quite easy to feed such modulation into an ultrasonic generator. The thermo-element should be very thin to be able to follow the low variations in intensity. There will then be produced in the thermo-element small a.c. voltages of low frequency proportional to the intensity of the ultrasonic vibrations.

These a.c. voltages are amplified in the Analyzer, tuned selectively to the low frequency. As a rule a very high amplification is needed, so the shielding and earthing must be done very carefully.

The set-up must be calibrated in a known field of intensity. Both the frequency and type of fluid medium influence the calibration.

This method has the great advantage that the excessively thin thermo-element in no way interferes with the field of sound, which is almost always the case with other methods.

General remarks on the Constant-percentage Bandwidth Analyzer versus the Heterodyne-Type.

With most acoustic and electroacoustic measurements it is preferable to carry out an analysis with an analyzer which has constant percentage bandwidth, i.e., one which selects a definite percentage of an octave, in preference to an

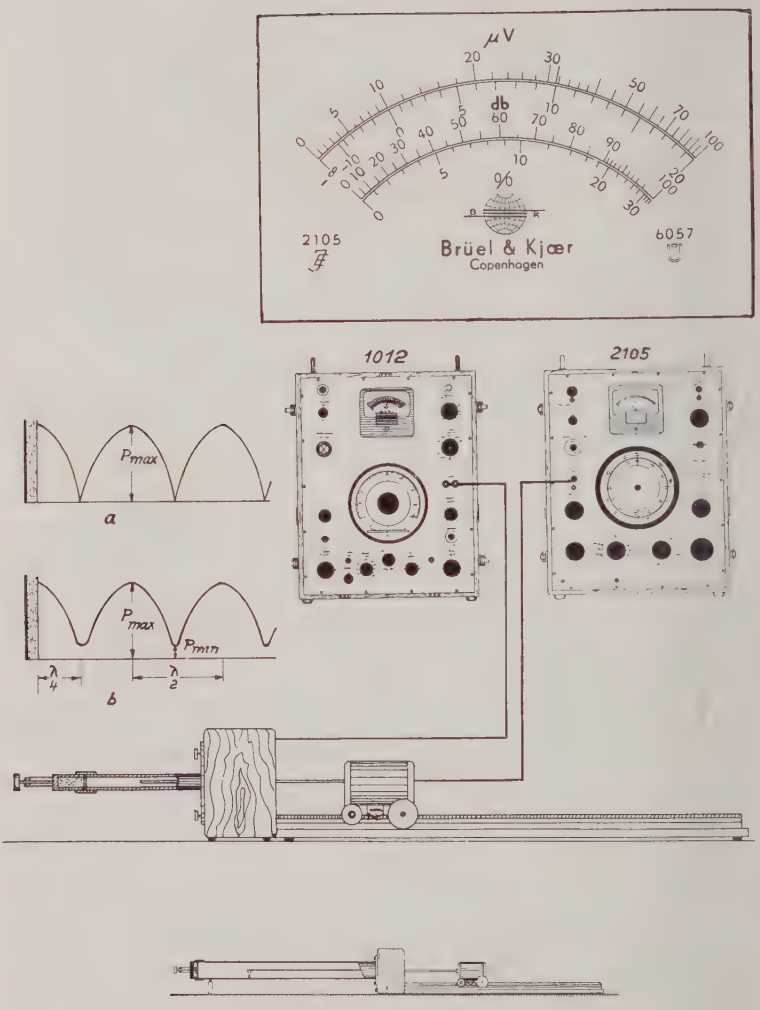


Fig. 30. Measurement of acoustic absorption coefficient.

analyzer of the heterodyne type which selects a definite frequency band. The ear's recognition of frequency is approximately logarithmic, so that whatever

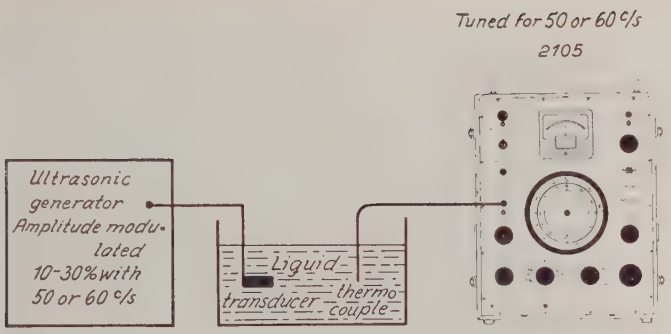


Fig. 31. Measuring ultrasonic intensity.

the ear recognises as consisting of high frequencies, covers a much greater absolute frequency band than that which is recognised as low frequencies. When the ear, therefore, judges a noise's character, that is, judges its spectrogram, it will automatically divide up the noise into octaves, and within each octave or part octave integrate the total sound pressure, just like a constant-percentage bandwidth analyzer, whether it is built as the type 2105 described here, after the degenerative principle, or is an analyzer consisting of filters.

On the other hand a heterodyne analyzer will select a definite absolute frequency band from the spectrogram, which band will, represented in the logarithmic scale, become smaller and smaller as one rises in the frequency range. From a purely physical point of view it is naturally indifferent which type of analyzer is used, as it is always possible, when the frequency is known, to make the necessary calculation involved in changing from the one type to the other. There is, however, one great disadvantage with the heterodyne analyzer, and that is the great difference between the spectrogram of a continuous noise and a noise with line spectra.

If a continuous noise is analyzed, for example the spectrogram of a typewriter as shown in fig. 32, the constant-percentage bandwidth analyzer will give the spectrogram shown above on the left, while the spectrogram of the same typewriter measured by the heterodyne analyzer will appear as shown above on the right, which appears very different from the first. The low end of the spectrogram is considerably accentuated, and the high end is quite depressed. The measured results from the heterodyne analyzer in no way correspond to the real subjective appreciation of the noise's composition.

The results are otherwise if the noise consists of a total of sharp distinct single frequencies, what is called a discontinuous spectrum or line spectrum as for example the tone from a 'cello, as measured below on fig. 32. With both the constant-percentage analyzer and the heterodyne analyzer the same values are measured for the harmonic amplitudes, so that the spectrogram has the same appearance no matter which type of analyzer is used.

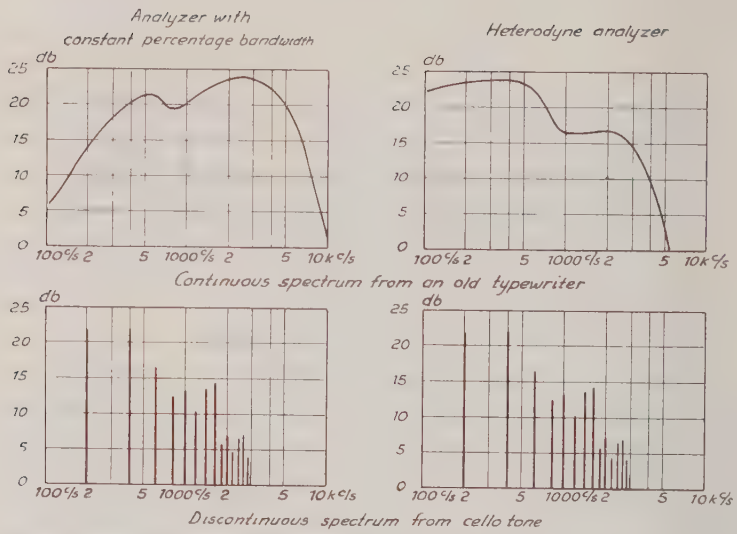


Fig. 32. Continuous and line spectrum measured with constant-percentage bandwidth analyzer and heterodyne analyzer.

As is seen in fig. 32 above on the right, spectrograms measured with the heterodyne analyzer exhibit very great level differences. As a rule the low frequencies will show exceedingly great sound pressures in relation to the high frequencies. This requires the heterodyne analyzer's selectivity to be great, if there shall be a fair degree of confidence at the high end of the spectrogram. The selectivity should not in practice be less than 80 db. This great selectivity demands a very long time constant in the analyzer, so that for this reason also the heterodyne analyzer is very slow to work with.

An advantage with the heterodyne analyzer is that it can be relatively easily coupled to a recorder in order to record spectrograms automatically. This advantage, however, becomes often illusory when the heterodyne analyzer's excessive slowness is considered.

The analysis of a noise which varies a little in frequency is almost impossible to carry out with a heterodyne analyzer, because the frequency variations at the higher frequencies are so great that the frequency lies within the band only part of the time. Therefore with unstable spectra too little is measured at the high end of the spectrogram. With the constant-percentage analyzer, however, the cutting down arising from frequency variation is the same for both high and low frequencies, so that the balance is correct and the appearance of the spectrogram is likewise correct.

As mentioned above, a constant-percentage analyzer does not need to be anywhere near so selective as a heterodyne analyzer. The lesser the selectivity that can be chosen, the quicker can the analyzer work, and the more stable the frequency characteristic it will show. For the acoustic analysis of noise the requirement is simply that it should be possible to separate out the frequency

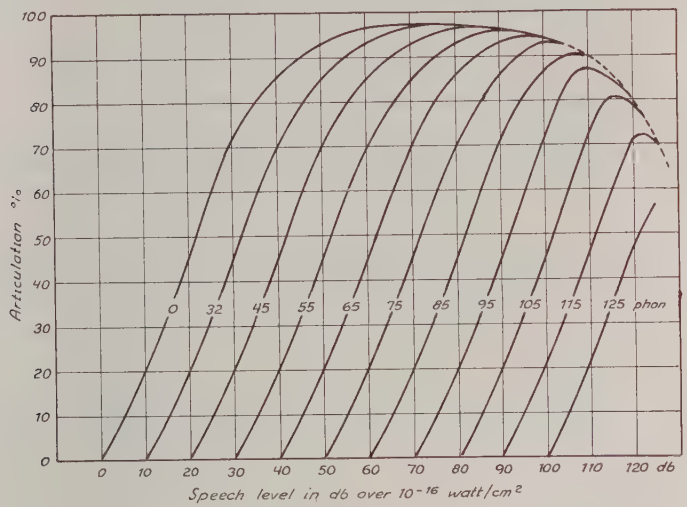


Fig. 33. Articulation in % (% correctly understood syllables) as function of disturbance when noise expressed in phons and speech level in db over $2 \cdot 10^{-4}$ μbar.

components of the noise which the human ear can just pick out, but the selectivity need not be much greater. The boundary is, however, not particularly sharp, as it depends much on the frequency separation of the partial frequencies, the relative composition of the noise and on whether the partial frequencies are harmonics. In speech, the influence on articulation, as shown in fig. 33, can be the basis for the considerations regarding the necessary selectivity. It will be seen in the figure that if the disturbing noise, which is given in phons, lies about 25 db above the speech level, the understandability is 0. One can, however, well perceive speech, with a background noise of slightly lower level. So if a maximum selectivity of 35 db is chosen, one is on the safe side.

Loudness and loudness level.

Loudness is a subjective quantity and cannot be measured exactly with any instrument. Loudness is defined as that aspect of auditory sensation in terms of which sound may be ordered on a scale running from "soft" to "loud". Loudness is chiefly a function of the sound pressure level, but it is also dependent on

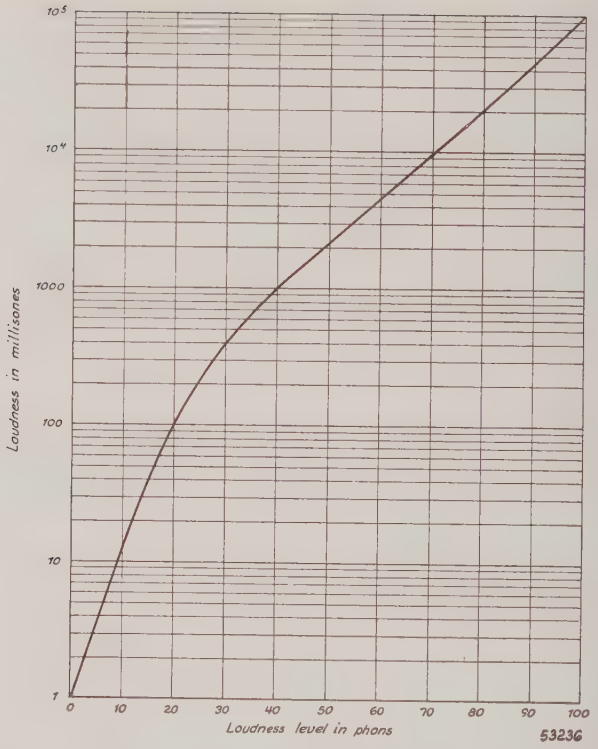


Fig. 34. Loudness in sones as function of the loudness level in phons.

the frequency and the composition of the sound. The loudness of a sound is related to the total wave energy produced by the sound in the ear, whence it is sent to the brain.

The range of loudness is divided subjectively into equal unit steps called sones = 1000 millisones = 1000 loudness units. A loudness of one millisone corresponds to the threshold of hearing and a loudness of 10 sones is twice as loud as a loudness of 5 sones and 10 times as loud as 1 sone etc.

The loudness of a sound at a given sound pressure level at one frequency may be quite different from the loudness of a sound of the same level at a different frequency, but listeners can adjust the level of one tone to match the loudness of another. By such experiments a useful objective scale of loudness, called loudness level, is made.

Loudness level of a pure tone in phons is numerically equal to the sound pressure level expressed in db above $2 \cdot 10^{-4}$ μbar of a 1000 c/s tone, which sounds equally loud.

Equal loudness contours for pure tones are shown in fig. 19.

The relationship between loudness in sones and loudness level in phons is given in fig. 34.

This curve applies to sound of any frequency, or combination of frequencies. If the loudness level of a sound is 40 phons, it will have a loudness of 1000 millisones, if the loudness level is 70 phons, it will have a loudness of 10000 millisones. A reduction of the loudness level from 70 to 40 phons corresponds to a tenfold change in loudness.

This relationship is of considerable practical interest in regard to the reduction of noise in rooms by sound absorption or by sound insulation. If, for example, the loudness level in a workshop by acoustical treatment of the ceiling is reduced from 72 phons to 63 phons, the average listener will judge the reduction from 12 to 6, which is the same as to the half or to 50 %.

Calculation of loudness level from line spectra.

If it is desired to calculate the loudness level in phons from a measured line spectrum consisting of a number of discrete frequencies, spaced relatively widely, the two charts fig. 19 and 34 are used. The procedure is as follows:

1) Determine from the chart fig. 19 the loudness level in phons of each discrete frequency according to the frequency and sound pressure in μbar.

2) Take the loudness level in chart fig. 34 and find for each discrete frequency the corresponding loudness in millisones.

3) Add the different values for loudness together.

4) Use this sum in fig. 34 to find the total loudness level in phons for the line spectrum.

Calculation of loudness level from continuous spectra.

With continuous spectra such as workshop noise, street noise etc., the calculation of loudness level in phons from the pressure measured as a function of the frequency is much more difficult than with line spectra.

It is best to procede by calculating from specially constructed families of curves, of which an example is shown in fig. 35, the contribution to the loudness in sones from each frequency band. The magnitude of this contribution depends in a complicated manner on both the sound pressure level in the band and the frequency. Fig. 35 is effective for ideal filters with a bandwidth of $^1/_3$ octave. (Similar families of curves, but less detailed, and effective for octave filters will be found on page 524 of L. L. Beranek's "Acoustic Measurements").

Having found a definite sound pressure in db above $2 \cdot 10^{-4}$ μbar for each filter, fig. 35 is taken and the corresponding number in millisones is found for each filter. The loudness total in millisones is then the sum of the contributions from the separate frequency bands. The loudness level is found by referring back to fig. 34.

With continuous spectra the energy is calculated as being directly proportional to the bandwidth expressed as a fraction of an octave (that is, not as an

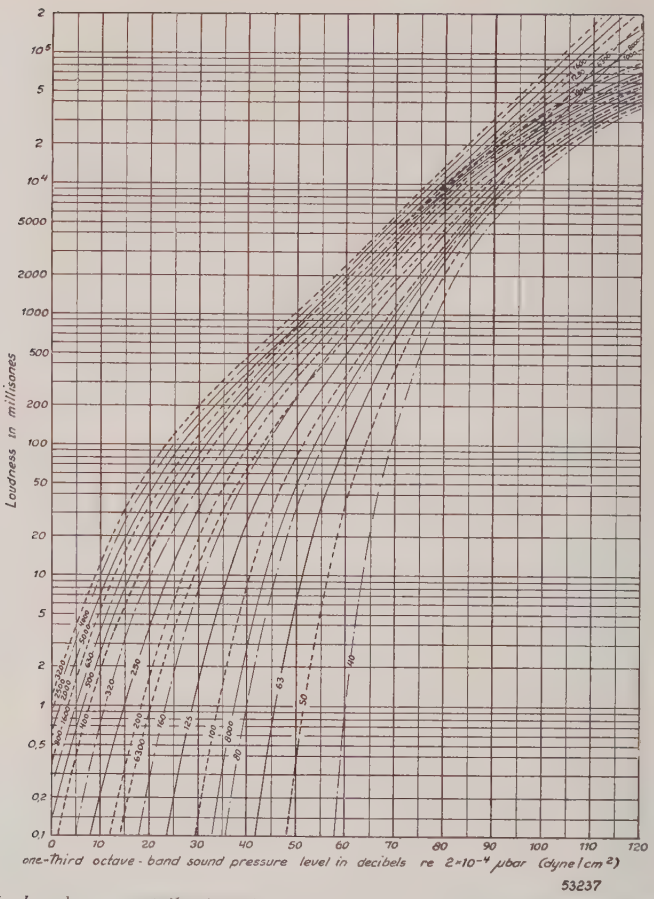
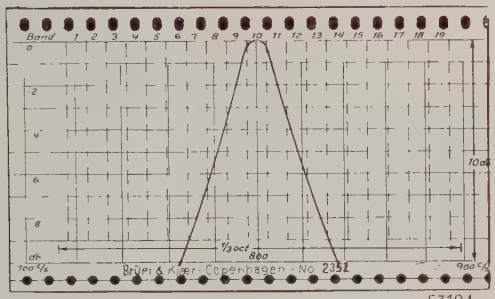


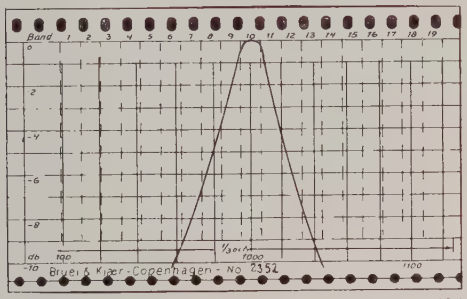
Fig. 35. Loudness contributions in sones as function of sound pressure level for ideal 1/3 octave filters.

absolute frequency band), on condition that the filters are ideal, i.e., have no damping in the pass band and very heavy damping outside this band.

With practical filters, the energy must be calculated by dividing the selectivity curve into a series of small bands and calculating the contribution from each separate band.

As an example, the correction factors will be calculated which should be added to the sound pressure as measured by Analyzer 2105, to obtain that sound pressure which would have been recorded if the measurements had been made with 1/3 octave ideal filters.





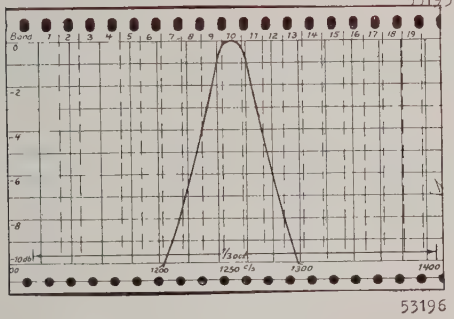


Fig. 36. Recorded selectivity curves for Analyzer 2105 Nr. 3428 made with Level Recorder type 2304 coupled to Beat Frequency Oscillator type 1012. 10 db potentiometer. The curves are recorded for frequencies 800, 1000 and 1250 c/s. Selectivity 35 db.

As mentioned previously the Analyzer's selectivity for variations within the same octave band is not completely constant because of variations in the impedance of the double-T network. Fig. 36 shows selectivity curves recorded for those frequencies 800, 1000 and 1250 c/s.

When drawn with a logarithmic frequency abscissa these curves are effective for frequencies lying whole octaves away from the value given.

Division band No.	Adjustment 800 c/s		Adjustment 1000 c/s		Adjustment 1250 c/s	
	db	energy	db	energy	db	energy
1	19.4	11	20.2	9	21.7	7
2	16.2	24	18.0	16	19.8	11
3	14.8	33	16.3	23	18.7	14
4	13.6	44	14.7	34	15.8	26
5	12.1	62	13.8	42	14.3	37
6	10.2	96	10.7	85	11.0	79
7	7.9	162	8.8	132	9.6	110
8	5.0	316	5.4	290	5.8	262
9	1.9	650	2.1	620	2.3	590
10	0	1000	0	1000	0	1000
11	1.9	650	2.1	620	2.3	590
12	5.0	316	5.4	290	5.8	262
13	7.8	166	8.7	135	9.6	110
14	10.0	100			11.0	79
15	12.0	63	10.4	91	14.2	38
16	13.4	46	14.5	36	15 6	27
17	14.6	35	16.7	21	18.2	15
18	16.0	25	17.8	17	19.3	12
19	19,2	12	20.2	9	21.4	7
Outside the 19 bands		45		35		30
Sum		3856		3505		3306

Table IV. Calculation of conversion-factors valid for white noise from Frequency Analyzer, selectivity 35 db, to an 1/3 octave ideal filter curve.

The curves are divided up by the dotted lines into bands 1/60 octave wide. The bands are numbered 1 -19 and 20 bands constitute 1/3 octave. The damping in db in relation to the mid-point is given in table IV as measured from the curves. and the energy in each band is calculated in ‰, when the energy in band Nr. 10 is taken as 1. The curves in fig. 36 cover only 10 db. Over that value the curves shown in fig. 6 are used. The energy contribution for all frequencies outside the 1/3 octave investigated is also calculated from fig. 6. With a selectivity adjustment of 35 db this contribution is seen to be almost without significance. The total energy in ‰ measured by the Analyzer is found by addition. This is compared to the total energy through the 1/3 octave ideal filter, which is 20, whereupon the correction factors are calculated as

$$K_{800} = 10 \cdot \log \frac{20}{3.856}\ \text{db}; \quad K_{1000} = 10 \cdot \log \frac{20}{3.505}\ \text{db}; \quad K_{1250} = 10 \cdot \log \frac{20}{3.306}\ \text{db};$$

Fig. 37 shows an example of a curve of impact sound measured with Analyzer 2105. The measured values are given on the lower curve, where it will be seen that the variable selectivity shows itself by a small variation in the values measured when changing octave ranges.

By correcting the sound pressures with the values found in table IV, the curve which is effective for 1/3 octave bandwidth, and which is shown below in fig. 37, will be obtained. From this curve, called the 1/3 octave band sound pressure level, and which is given in db above $2 \cdot 10^{-4}$ μbar, the loudness can be calculated by means of fig. 35. The middle frequencies for the imagined 1/3 octave filters are given with the vertical black lines in fig. 37. The calculations are as shown in table V below.

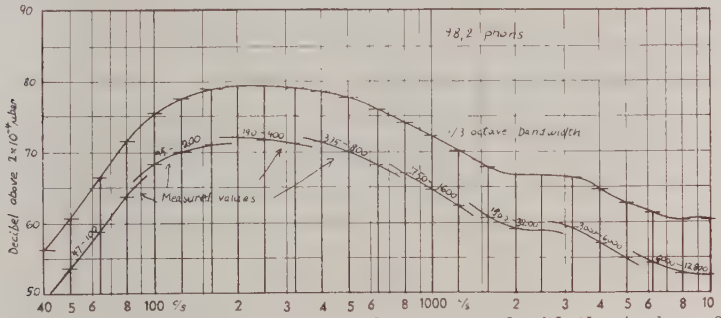


Fig. 37. Spectrogram of impact sound as measured with the Analyzer 2105 and calculated for 1/3 octave bandwidth.

Another method has been developed by Bell Telephone Laboratory for the calculation of loudness level from continuous spectra, where reduction to 1 c/s bandwidth has been used (pressure spectrum level). From this, a so-called masking spectrum is determined, which is set out on a special graph paper. The area under the curve is calculated and is an indication of the loudness in sones. (See, for example, V. O. Knudsen and C. Harris, "Acoustical Designing in Architecture", John Wiley & Sons, 1950).

Frequency c/s	db above 2.10^{-4} μbar	millisones	Frequency c/s	db above 2.10^{-4} μbar	millisones
40	56	0	800	74	6200
50	61	50	1000	72	5000
63	67	400	1250	70	4400
80	73	1200	1600	68	3600
100	76	2100	2000	67	3500
125	78	3200	2500	67	4000
160	78	3500	3200	67	4200
200	79	5500	4000	65	3400
250	79	6000	5000	63	2600
320	79	6600	6300	62	800
400	78	6800	8000	60	250
500	78	7000	10000	61	40
630	76	6200	Sum	98.2 phons	86540

Table V. Calculation of loudness level of spectrogram of fig. 37.

Specification of Frequency Analyzer type 2105.

Frequency Range: 47—12000 c/s in 8 ranges. The exact frequencies are read directly on the illuminated main scales.

Selectivity: Variable in 5 steps marked 20—25—30—35 and max. The figures are the attenuation one octave off the peak to which the analyzer is tuned. Maximum position corresponds to 40 db making possible distortion measurements down to about 1 %.

Frequency Accuracy: Better than 1 %

Frequency Response Characteristics: As a linear amplifier in the frequency range from 30 to 15000 c/s and as an analyzer, the amplification of the adjusted frequency is constant within ± 1 db (except for max. selectivity where the accuracy is slightly lower). As a sound level meter the frequency response characteristics are the internationally proposed characteristics at 30—60 phons and 60—130 phons.

Amplification: Max. amplification gives full deflection for 100 microvolts and may be attenuated in steps of 20 db. Input potentiometer for continuous variation.

A.C.-hum: Approximately 2 microvolts, referring to the input terminals at maximum gain.

Meter: Logarithmic scale, conveniently illuminated. Perfectly safeguarded against overload.

Scales: From 0 to 100 microvolts and from —10 to +20 db. A percentage scale intended for the measurement of acoustical absorption coefficients in connection with the Standing Wave Apparatus 4002.

Connection to Condenser Microphone 4111 and Artificial Ear 4109: These apparatus can be connected directly to the analyzer and all necessary voltages are supplied by the analyzer. Noise levels down to 11 phons are measurable in selective position. It is possible to have a long cable between the microphone and the analyzer on account of a built-in cathode follower tube in the microphone.

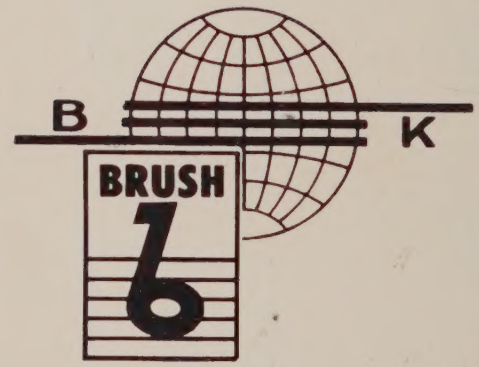
Connection to Frequency Measuring Bridge and Blocking-Network 1602: When the blocking network is connected in order to block out the fundamental it is possible to analyze the harmonics of the input voltage down to 0.01 %.

Tubes: 4 · 6AU6 (EF94), 6X4 (EZ90) and OA2 (150CIK).

Power Supply: 115—127—150—220 volts a.c. Consumption approximately 45 watts.

Cabinet: Mahogany cabinet with handles and lid. Power cable in the lid.
Dimensions: 50 (height) · 40 (width) · 20 (depth excl. dials) centimeters.
20 (height) · 40 (width) · 8 (depth excl. dials) inches.

Weight: 18 kg or 40 lbs.



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